QUSSAI OMARI

VIABILITY STUDY OF GRID-CONNECTED ROOFTOPS SOLAR PV SYSTEM FOR DIFFERENT COASTAL CITIES IN LEBANON

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VIABILITY STUDY OF GRID-CONNECTED ROOFTOPS SOLAR PV SYSTEM FOR DIFFERENT COASTAL CITIES IN LEBANON

**A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES
OF
NEAR EAST UNIVERSITY**

**By
QUSSAI OMARI**

**In Partial Fulfillment of the Requirements for the Degree of Master
in
Mechanical Engineering**

NICOSIA, 2020

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Master of Science in Mechanical Engineering

Examining Committee in Charge:

Assoc. Prof. Dr. Kamil DİMİLİLER — Committee Chairman, Department of Automotive Engineering, NEU

Assist. Prof. Dr. Youssef KASSEM — Supervisor, Department of Mechanical Engineering, NEU

Assoc. Prof. Dr. Hüseyin ÇAMUR — Department of Mechanical Engineering, NEU

I hereby declare that, all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: Qussai Omari

Signature:

Date:

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Further, I would like to express our feeling towards my parents who directly or indirectly encouraged and motivated us during this dissertation

To my parents….

ABSTRACT

With of the increasing consumption of fossil fuel, reducing greenhouse gas (GHG) emissions has become a serious issue that has attracted worldwide attention. Therefore, lebanon is currently interested in utilizing renewable energy technologies to reduce the energy dependence on oil reserves and GHG emissions. This study is assessed the potential of utilizing of grid-connected rooftop solar PV power generation in Lebanon particularly in five selected coastal cities namely, Batroun, Beirut, Tripoli, Sidon and Tyre. The input data source for the study includes Solar Energy Dataset of NASA. RETScreen Experts software is employed in the study. The results found that the average capacity factor of the solar PV plant of the different cities considered is 20.6% and the mean value for the electricity exported to the grid is 21.8 MWh/year. Moreover, economic viability study of small-scale 12kW grid-connected rooftop PV project in all selected cities is conducted. Financial indicators showed that the proposed solar PV system is economically viable, but it may not be sufficiently attractive for commercial investors unless an incentive mechanism is introduced. Also, the results indicated that, residential PV system is feasible at the current electricity tariff.

Keywords: Lebanon; solar system; grid-connected; small-scale; economic analysis

ÖZET

Artan fosil yakıt tüketimiyle birlikte, sera gazı (GHG) emisyonlarını azaltmak dünya çapında dikkat çeken ciddi bir sorun haline gelmiştir. Bu nedenle, Lübnan şu anda petrol rezervlerine ve sera gazı emisyonlarına enerji bağımlılığını azaltmak için yenilenebilir enerji teknolojilerini kullanmakla ilgileniyor. Bu çalışma Lübnan'da özellikle Batroun, Beyrut, Tripoli, Sidon ve Tire olmak üzere seçilen beş kıyı kentinde şebekeye bağlı çatı güneş PV güç üretiminin potansiyelini değerlendiriyor. Çalışma için girdi veri kaynağı NASA'nın Güneş Enerjisi Veri Kümesini içerir. Çalışmada RETScreen Experts yazılımı kullanılmıştır. Sonuçlar, farklı şehirlerdeki güneş PV santralinin ortalama kapasite faktörünün% 20,6 olduğunu ve şebekeye ihraç edilen elektrik için ortalama değerin 21,8 MWh / yıl olduğunu bulmuştur. Ayrıca, seçilen tüm şehirlerde küçük ölçekli 12kW şebekeye bağlı çatı PV projesinin ekonomik uygulanabilirliği çalışması yürütülmektedir. Finansal göstergeler, önerilen güneş PV sisteminin ekonomik olarak uygulanabilir olduğunu, ancak bir teşvik mekanizması getirilmediği sürece ticari yatırımcılar için yeterince çekici olmayabilir. Ayrıca, sonuçlar, mevcut elektrik tarifesinde konut PV sisteminin uygulanabilir olduğunu göstermiştir.

Anahtar Kelimeler: Lübnan; Güneş Sistemi; şebekeye bağlı; küçük ölçekli; ekonomik analiz

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INTRODUCTION

1.1 Background

Climate change is a huge environmental disaster that endangers the quality of life on earth's crust (Burton, 2019). This phenomenon is also known as global warming. It means the global warming dramatically and transforms it into a greenhouse, that is, to retain heat and increase its surface temperature (Daniels, 2009). This phenomenon was clearly seen in the mid-twentieth century, and serious work has begun to find appropriate solutions to eliminate it and minimize its negative impacts. (Daniels, 2009; Burton, 2019).

Continued environmental developments are likely to contribute to global warming, the depletion of strategic oil reserves and continuing challenges to a future issue of access to power, all of which have recently contributed to the consideration of renewable energy sources, including wind.

Wind power is a local renewable energy source and does not produce greenhouse gases, such as methane, nitric oxide and carbon dioxide (Chanda and Bose, 2019; Chen et al., 2019; Rogers et al., 2019). Turbines are devices that used transform wind energy into electrical energy and can be assembled in tall buildings (Caglayan et al., 2019; Ahmad et al., 2018; Cali et al., 2018; Murray et al., 2019).

Wind power is the method of changing wind movements to another form of energy that is easy to use. Wind energy is the method of changing the wind to another form of energy that is easy to use (Caglayan et al., 2019; Ahmad et al., 2018; Cali et al., 2018; Murray et al., 2019). Energy that can be used directly in pumps, grinding, or turbine recycling to generate electricity Increased awareness of changes in the global climate has increased the importance of renewable energies, increasing the demand for wind energy.

1.2 The Concept of Renewable Energy

Energy is an integral component of the world and a source of life. Energy is typically based on natural and unusual sources, and is thus divided into two main types: renewable energy, which relies on natural and non-renewable resources and is dependent on abnormal sources, but produced over time and under the influence of a number of factors (Paletto et al., 2019; Nazir et al., 2019; Topcu and Tugcu, 2019). All sorts of such energy require the existence of special structures, devices and strategies for obtaining and harnessing them for the benefit of mankind. Within this research subject, we will shed light on renewable energy and everything related to it.

Renewable energy is energy extracted from, and not depleted from, the natural resources of the environment. It generates renewable energy from wind, sun and water, in addition to energy from tides or geothermal energy. Renewable energy is eco sustainable energy, unlike renewable power based on fossil fuels and petroleum, which causes damage to the environment, contributes to climate change, and also causes environmental pollution due to its waste, which has affected the lives of living organisms on the surface of the earth, including humans, and has caused many health problems, and caused him many health problems, and appeared a lot of Diseases that were not present before, and it caused a lot of health issues, and a lot of diseases arose that had not been present before.

1.3 Advantage of Renewable Energy

Renewable energy has a number of advantages over combustion of fossil fuels such as (Nelson and Starcher, 2018)

- Renewable energy is an inexhaustible energy.
- Provides renewable energy free from impurities, waste and contaminants.
- Maintains public wellbeing.
- Energy is considered to be environmentally friendly and does not cause any harm.
- Provides a number of job opportunities for people who are unemployed.
- Its value is simple and low compared to some other types of energy.
- Significantly reduces the risk of natural disasters caused by global warming
- Do not cause the production of acid rain harmful to plants.
- They protect various species, especially those that are endangered.
- Protects groundwater, seawater, rivers and fisheries from pollution and extinction.

- Contribute to food security.

1.4 Renewable Energy Sources

There are several natural renewable energy sources, the most popular of which is the following (Nayeripour and Kheshti, 2011; Kemp, 2005; Dorsman André et al., 2014)

Wind energy

Wind energy: is the conversion of the kinetic energy generated by the rotation of wind fans by the impact of wind, which in turn move the turbines we get through the rotational movement of electric power as shown in Figures 1.1 and 1.2.

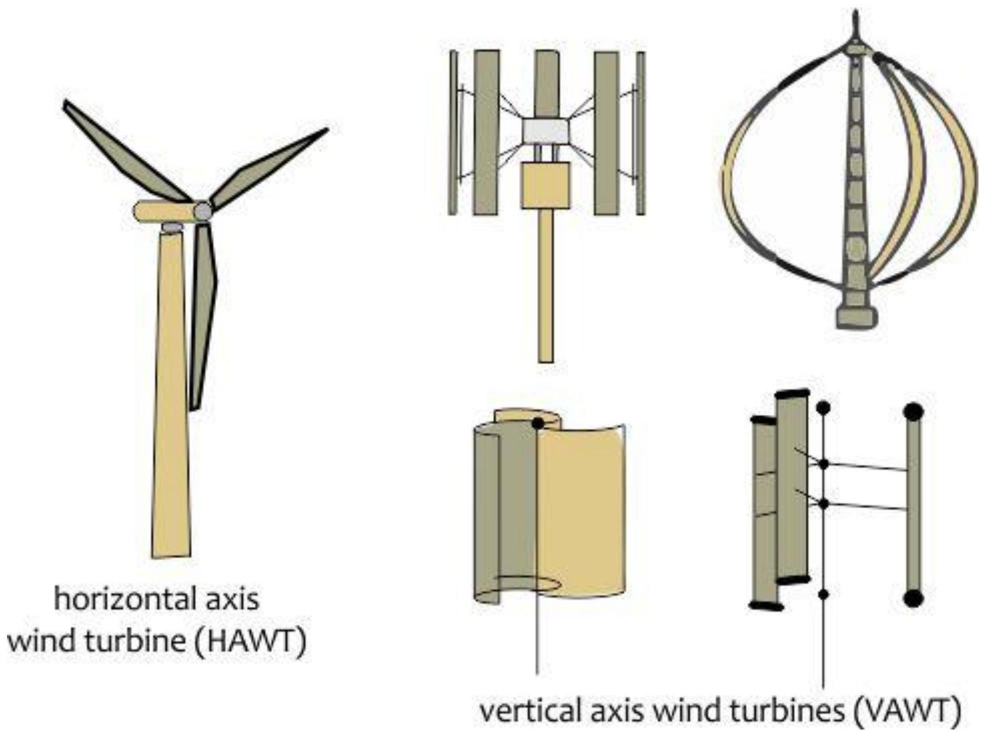

Figure 1.1: Horizontal and vertical axis wind turbine

Geothermal energy

Geothermal energy: is the exploitation of heat energy stored under the surface of the earth in the heating processes in the near-surface layers or the generation of electrical energy through the transfer of high heat to steam turbines in the deep layers (see Figure 1.2).

Figure 1.2: Geothermal energy

Biogas

Biogas: Methane is obtained from fermentation of animal or plant waste (biomass). Biogas is used as an alternative to natural gas in electricity generation, water heating or even in domestic uses (Figure 1.3).

Solar energy

Solar power: the transformation of sunlight (light + heat) to earth into heat or electrical energy (Figure 1.4).

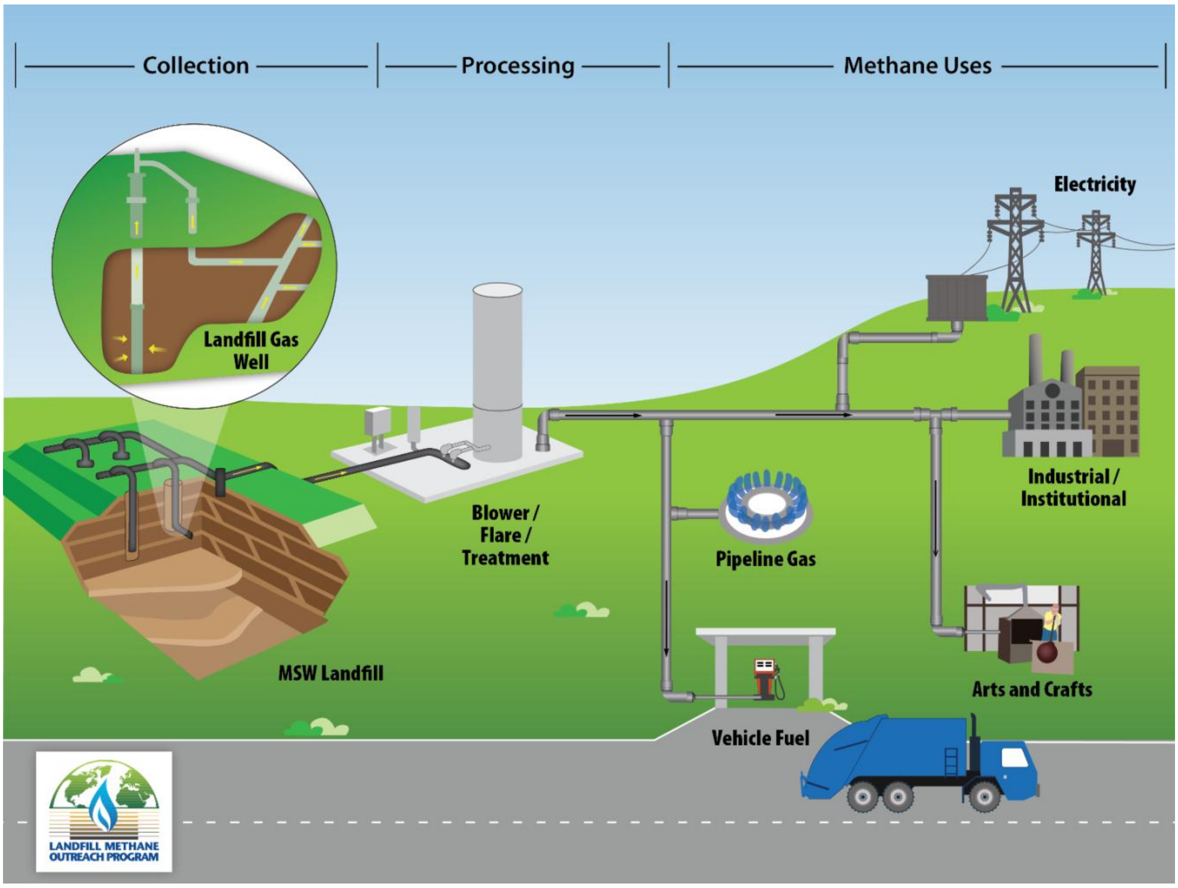

Figure 1.3: Biogas procedure

Figure 1.4: Solar energy

1.5 Aim of the Study

Regarding the research study, there is a clear lack of assessment of solar potential in coastal cities, including Batroun, Beirut, Tripoli, Sidon and Tyre, Lebanon. Besides that, there seems to be a clear lack of exploration of the potential of small-scale grid-connected residential and commercial rooftop solar PV systems generation in selected cities. Therefore, the objective of this paper is to the potential of exploiting solar energy in five coastal cities in Lebanon based on NASA database. Additionally, this study sets out the technological, environmental and economic aspects of the 12kW small-scale grid-connected rooftop PV system for cities in Lebanon in order to provide a solution to meet the increasing demand for energy and to improve life standard in urban areas due to rapid urbanization of the region. In addition, production of electrical using solar systems can protect the environment for Lebanon. For this purpose, RETScreen Expert software is utilized to validate the techno-economic 12kW grid-connected rooftop solar PV system in the cities.

1.6 Research Outline

The importance of renewable energy to the world is discussed in this chapter. The importance of solar energy and the type of solar panel are presented in Chapter 2. Moreover, the methodology that used to evaluate the solar potential and design a 12kW PV system for generating electricity in the selected region is explained in Chapter 3. In Chapter 4 all test results are displayed for the proposed system. On the end of the dissertation, the conclusions are presented in Chapter 5.

CHAPTER 2
SOLAR ENERGY POTENTIAL AND LITERATURE REVIEW

2.1 Types of Energy Sources

2.1.1 Non-renewable energy

Non-renewable energy sources have been formed over millions of years due to geological processes (Kang et al., 2019). It is noteworthy that their use is faster than the use of natural energy sources, which made it more reliable than renewable energy sources, such as fossil fuels, oil, and natural gas as shown in Figure 2.1.

Natural gas

Natural gas is often made up of methane, and is found near other fossil fuels, such as coal, produced by methane generation in landfills and marshlands. When it burns, it produces half of the greenhouse gas emissions.

Petroleum

Petroleum or crude oil is defined as a toxic flammable liquid that occurs in geological formations underground, used as fuel oil and gasoline, but is likely to be present in the components of medicines, plastics, and kerosene.

Coal

Coal is a sedimentary rock produced in marshes, where organic matter accumulates from plants, and the aggregation of these materials forms a substance known as peat, which releases volatile components, such as water and methane, resulting from the pressure from peat, and then coal is produced. Coal is also the most widely used fossil fuel in the world to produce electricity. In the United States, about 93% of coal consumed is used to generate electricity, and coal combustion produces almost three times the amount of CO_2 emissions.

Nuclear Energy

Nuclear energy is emitted at nuclear fission, the split of the nucleus of an atom. Nuclear power is a common method of generating electricity worldwide. Although it is a common mineral found in rocks around the world, nuclear energy has many disadvantages, such as the production of radioactive materials. Radioactive waste can be highly toxic and they also increase the risk of blood disease, cancer and bone caries among people at risk.

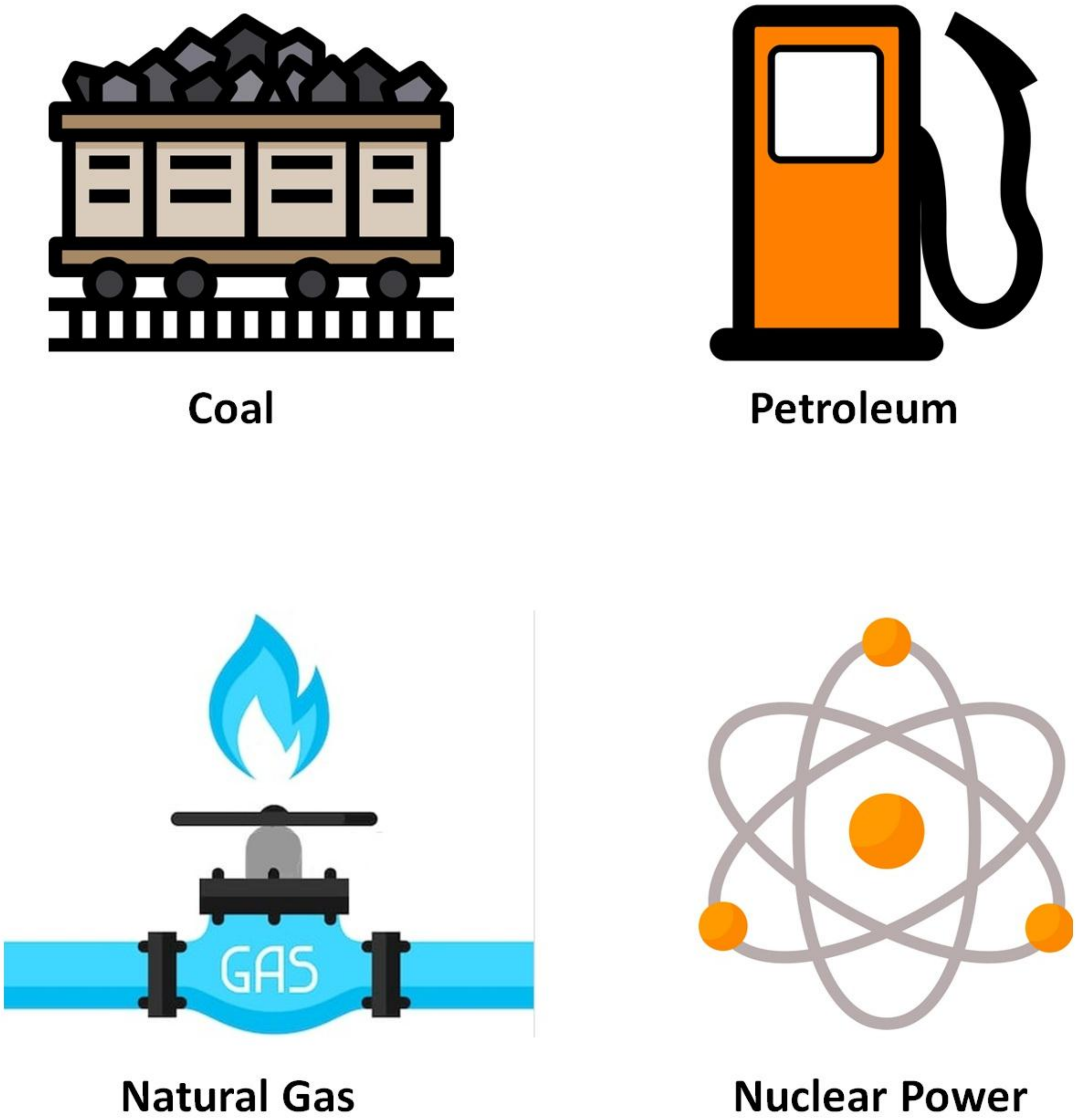

Figure 2.1: Non-renewable sources

2.1.2 Renewable energy

Renewable energy sources are clean sources and are not depleted due to human consumption. Renewable resources include wind, solar, thermal, hydroelectric, and others, with lower greenhouse emissions and other emissions.

Renewable Energy (Figure 2.2), a type of energy that is inexhaustible and depleted and the name indicate that whenever it is nearing completion exists again and comes from one of the natural resources, such as wind, water, sun. The most important characteristics of renewable energy (Toklu, 2013) are

1. A clean and environmentally friendly energy,
2. Does not leave Harmful gases, such as carbon dioxide,
3. Does not adversely affect the surrounding environment and
4. Does not play a significant role in temperature levels.

Renewable energy sources are in stark contrast to their non-renewable sources, such as natural gas and nuclear fuel, which lead to global warming and the release of carbon dioxide when used.

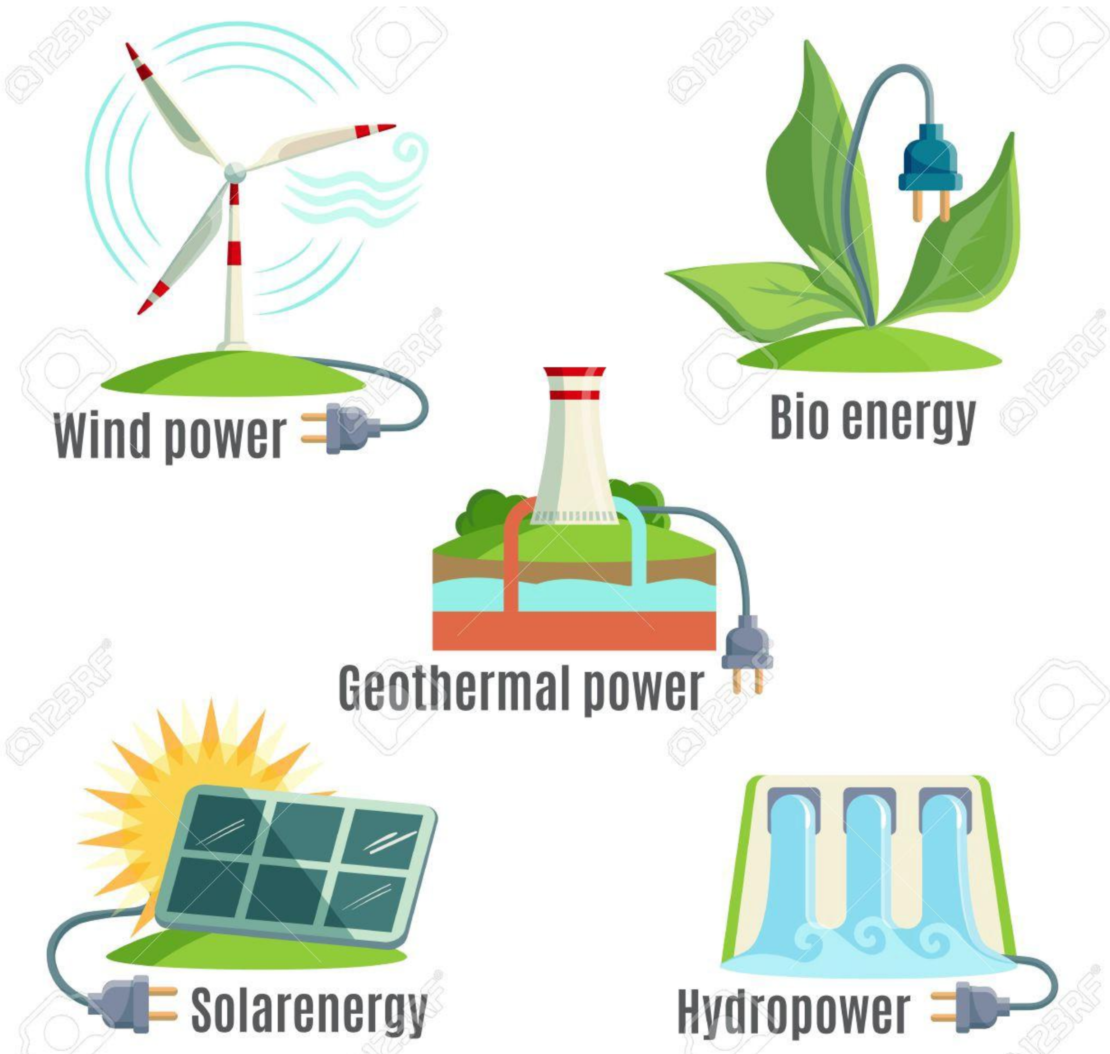

Figure 2.2: Renewable energy sources

There are a number of advantages that renewable energy has, and makes it a distinct source of energy.

1. Renewable energy is environmentally friendly and clean.
2. They exist permanently and are renewable again.
3. Easy to use using simple techniques and mechanisms.
4. It is very economical.
5. It is an important factor in environmental, social and all fields' development.
6. Helps mitigate the effects of gaseous and thermal emissions.
7. Prevents harmful acid precipitation. Limit waste collection in all its forms.

8. Cultivation is free of chemical contaminants, thus increasing agricultural productivity.
9. It uses uncomplicated technologies and can be manufactured locally in developing countries.

2.2 Solar Energy

The Sun, or the core of the solar system, is the closest star to Earth, estimated at 26,000 light-years. The star is estimated to be 4.5 billion years old. The massive gravity in the Sun is responsible for the stability of the solar system so that all components of the solar system are fixed from large planets too small parts of each Orbit.

Solar energy, the energy emitted by the sun's rays, is mainly in the form of heat and light, is the product of nuclear reactions within the star closest to us, the Sun. This energy is of great importance to the earth and the organisms on its surface. The amount of this energy produced far exceeds the current energy requirements in the world in general, and if properly harnessed and exploited may meet all future energy needs.

The importance of solar energy lies in the fact that the sun’s rays have facilitated the evolution of organisms and is responsible for photosynthesis in plants to produce food and biomass, in addition to the role of these rays in hydropower and wind power. In addition, solar energy is responsible for the so-called renewable energy group, the most important of which is the increasing importance of solar energy as a source of energy.

Scientific researcher's studies are increasingly interested in renewable energy sources because of the growing concerns around the world due to climate change. Renewable energy is characterized by its ability to replenish and not deplete resources. There are a number of disadvantages to renewable energy, as they are limited inflow. This means that energy is not accessible at any time.

In general, this energy is the production of heat by converting the energy inherent in sunlight. This energy attracts the heat of the sun and its photovoltaic cells and transports it to a water cycle to provide homes with hot water or heating. There are several methods for the efficient use of solar energy, which can be classified into three main categories: thermal applications, electricity production and chemical processes, and the most widely used applications in the field of water heating. Electricity is currently being generated by photovoltaic systems and solar thermal technologies, based on the conversion of sunlight into electricity using solar panels (see Figure 2.3). The benefits of photovoltaic cells lie in their ability to convert solar energy directly into electricity and in its ease of use, making it usable, especially in developing countries where there are no large generators.

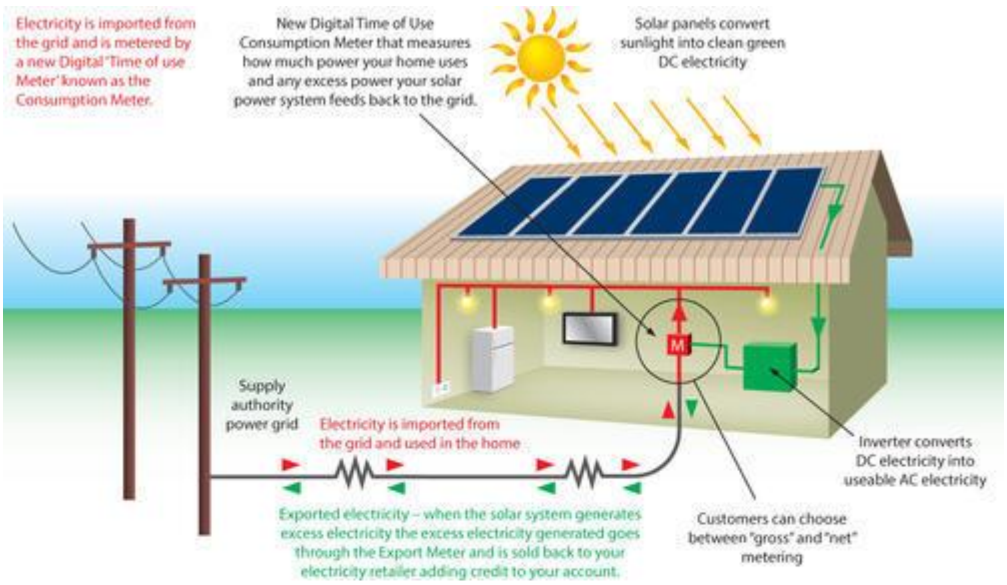

Figure 2.3: Grid-connected solar energy system

2.2.1 Advantage of solar energy

Solar energy is the most abundant and freest source of energy, and humans use it in many of their daily activities.

1. Costs for homeowners and real estate can be reduced through the use of solar energy.
2. Many jobs are available due to the increase in companies in the renewable energy sector.
3. Solar plants are environmentally friendly compared to nuclear power plants, by reducing emissions of harmful chemicals to the environment.
4. Excess energy can be stored and distributed in months that do not receive much sunlight.

5. It has the potential to innovate and develop compared to the methods of producing energy from other sources.
6. Cars can use solar energy instead of fuel, eliminating the need for oil.

2.2.2 Disadvantage of solar energy

It is undeniable that solar energy is one of the most important sources of energy. However, it is not without its negatives. The following are the main downsides of solar energy

1. The large cost of solar panels to produce large amounts of energy.
2. Recycling solar panels is considered to be a cause of water pollution, as this negativity can be avoided if organic materials are used in the manufacture of solar panels.
3. Relying on battery systems during the night and times when panels cannot absorb enough solar radiation.
4. Solar energy systems take time to become mainstream and widely accepted as an alternative to energy production.

2.2.3 Solar Energy uses

Solar energy can be converted into electrical energy and thermal energy through photovoltaic conversion and thermal conversion of solar energy as follows (Greeley, 1979; Foster et al., 2010):

Solar thermal uses

- Solar water heating

It is an integrated system consisting of several parts used to collect the solar radiation falling on them and converted into heat energy to be used to heat water during the hours of sunshine where hot water is stored in a heated tank for use during the day as shown in Figure 2.4.

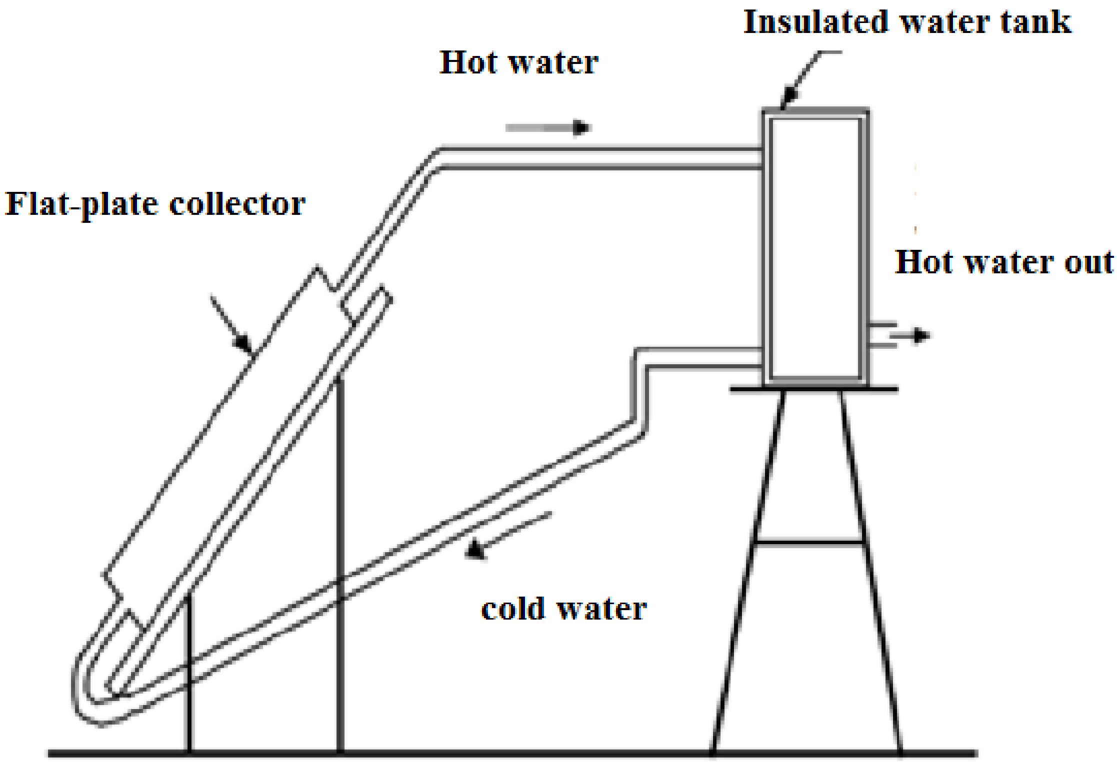

Figure 2.4: Solar water heating

- Solar swimming pool heating

Solar water heaters can also be used to heat the pool water (Figure 2.5). Solar collectors heat pool water to temperatures slightly above ambient temperature For this purpose, cheap unglazed solar collectors, which are usually made of plastic materials specifically designed for this purpose are used for the heating of pool water.

Figure 2.5: Solar swimming pool heating system

- Sewage Treatment

Solar energy is also used to remove toxins from contaminated water using photo degradation.

- Solar cooking

The solar cooker is a device that uses sunlight to cook, dry and pasteurize. For example, Figure 2.6 shows the parabolic solar cooker.

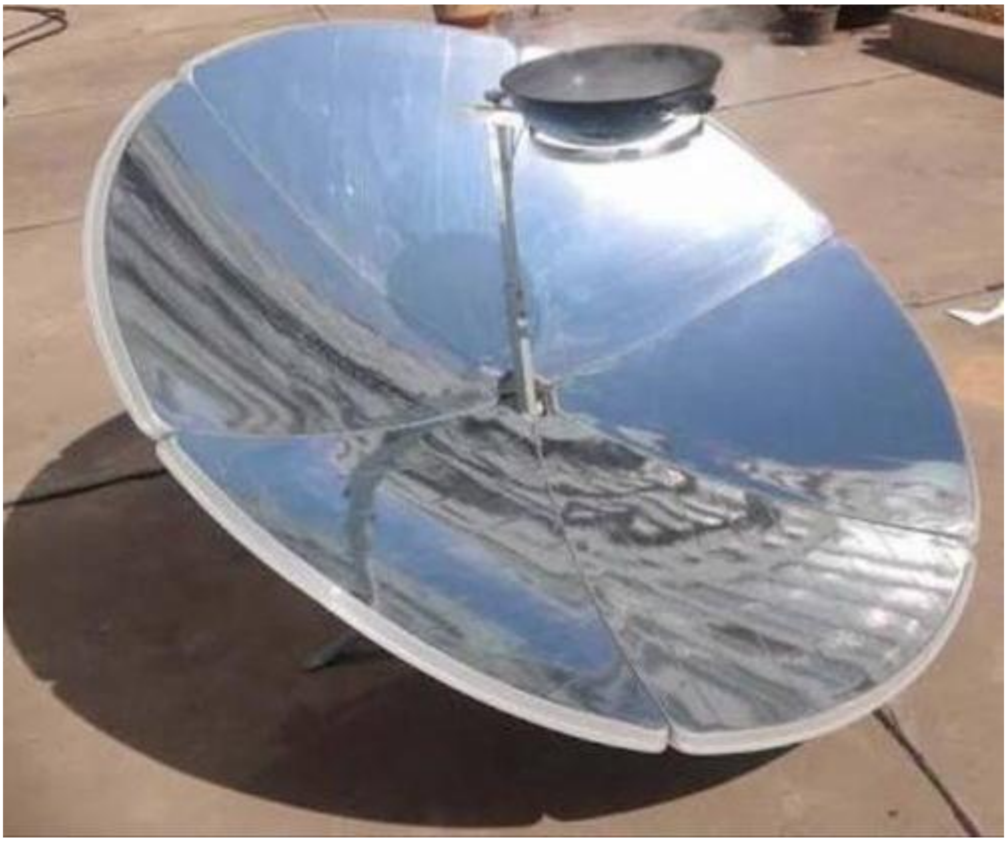

Figure 2.6: Parabolic solar cookers

Use of solar energy to generate electricity

Electricity is one of the energy carriers that can be used for many purposes. Solar energy can be converted into electrical energy through photovoltaic conversion. It is intended to convert solar or light radiation directly into electrical energy using photovoltaic solar cells as shown in Figure 2.7.

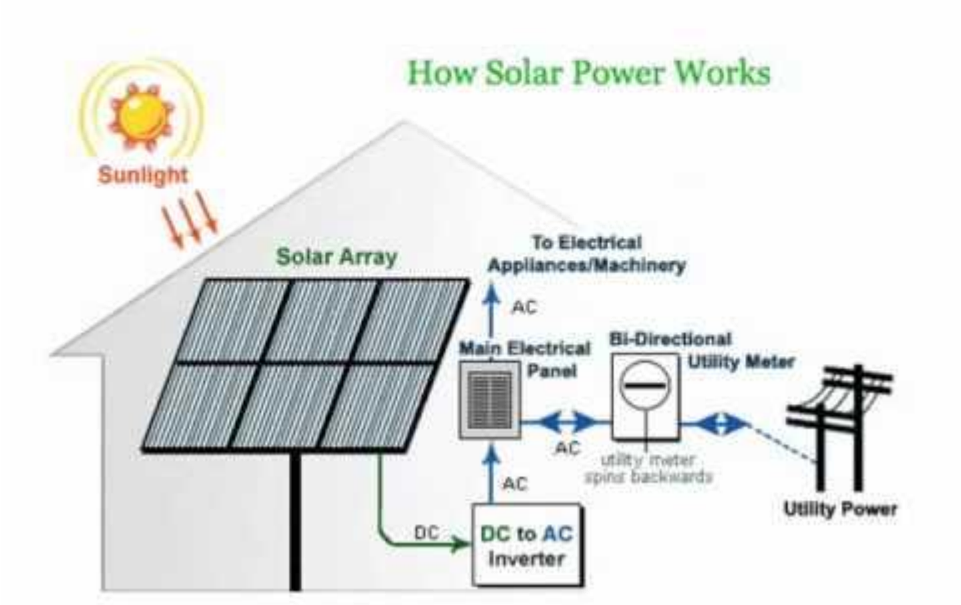

Figure 2.7: Use of solar energy to generate electricity

2.2.4 Solar panels work (Photovoltaic)

With the increasing interest in renewable energies in general and solar energy in particular, there have been attempts to provide solar energy technologies with an amount of energy equal to or close to the amount of energy spent (Chel and Kaushik, 2018). It has become popular, transforming buildings from energy-consuming plants into productive buildings that rely on the sun as an economical source of energy, and are commonly used even in areas with high levels of solar radiation or areas characterized by short hours of sunshine.

The solar system for electric power generation consists of four basic elements as follows (see Figure 2.8):

- PV photovoltaic
- Charger controllers
- Invertors
- Batteries

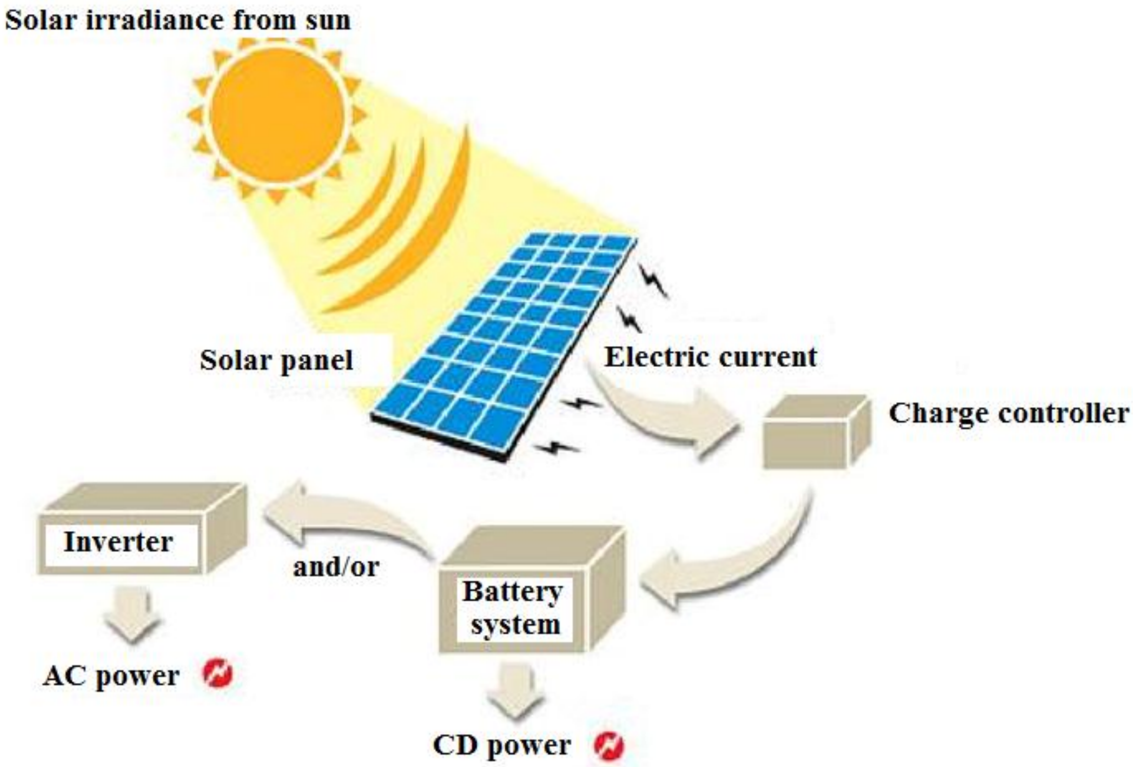

Figure 2.8: Elements of PV system

1. PV photovoltaic

It is the visible part of the solar system that is installed on the roof of the building and it is used to generate electric power. The components of solar panels are shown in Figure 2.9. The solar panel is solar cell grouped together produce DC electricity that can be used to operate some equipment or stored in batteries recharged, which can be used more than once. The unit of the measured power of the cells is Watt.

To illustrate how solar panels work, the main component of the solar system which is the solar cell is explained.

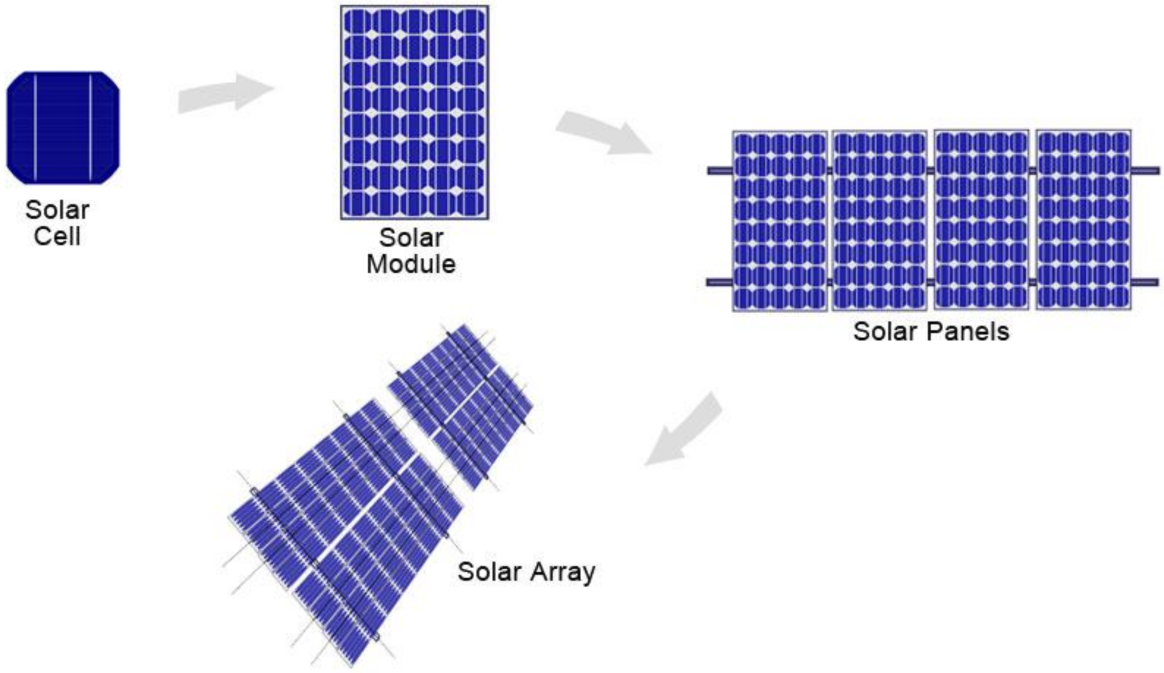

Figure 2.9: Components of PV panel

PV cell

It is the main component of the solar system and is the smallest part of it. They respond to direct and indirect solar radiation by converting radiation energy into electrical energy. Solar panels take advantage of sunlight that activates electrons within a cell to produce current (Marsh, 2019). Photovoltaic cell consists of semiconductors; often elections that are compressed into a specially treated chip to form an electric field, positive on one end and negative on the other end (see Figure 2.10) (Marsh, 2019).. Electrons are stimulated to a higher state of energy to generate electricity, and electrons are collected as electric current if electrical conductors are connected to the negative and positive ends (Marsh, 2019).. The resulting electrical energy is DC energy and that energy is stored in batteries of different capacity so that it can be used during the sun's demise (Marsh, 2019).

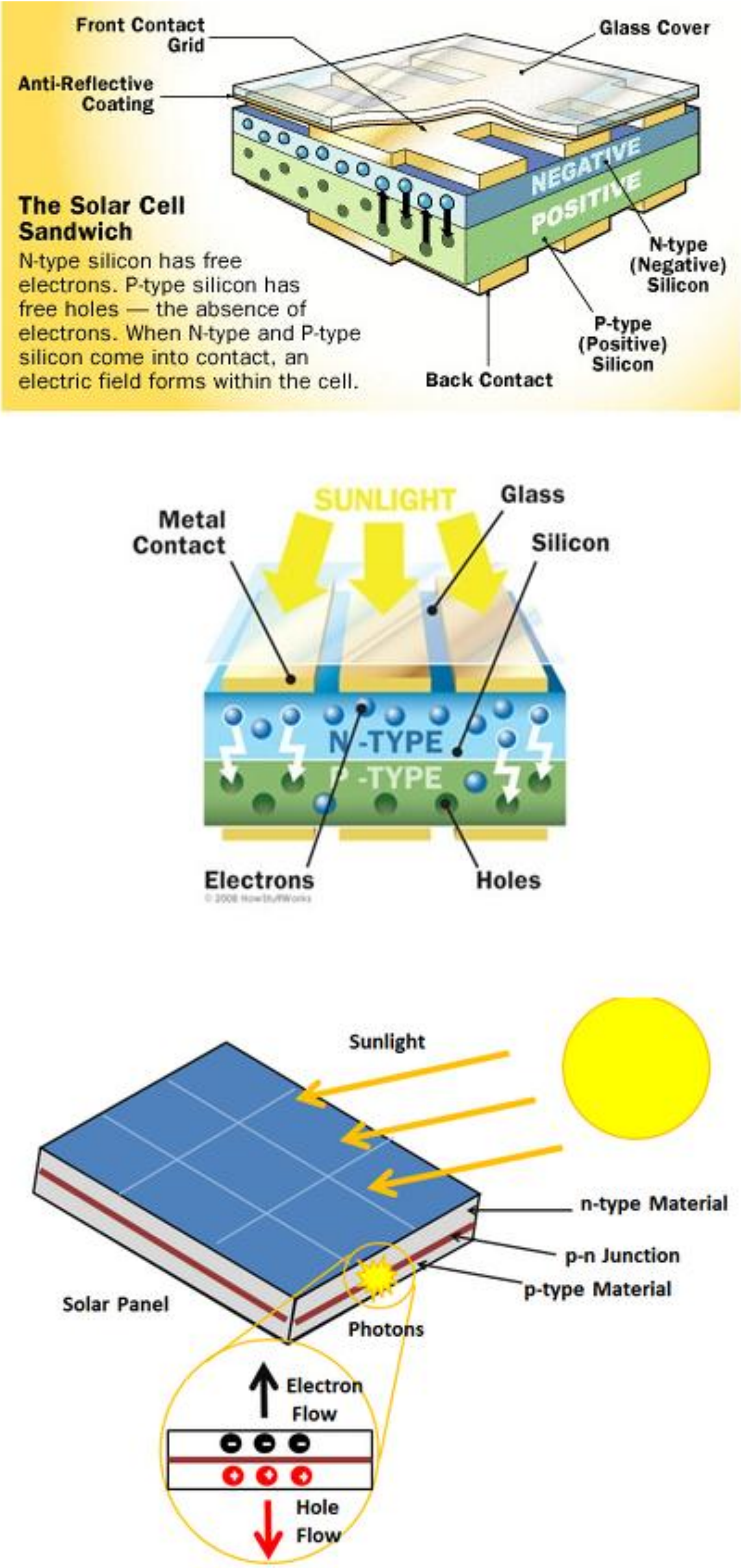

Figure 2.10: PV cell working principle

Initially, the solar cells, which are placed directly under the sun, absorb these rays and convert these rays to electrical energy for human use in many purposes and fields, and thus serve as sunlight alternative to what normal generators do, when the sun shines, which contains large energy Here, solar panels attract this energy, which contains many solar cells arrayed next to each other, and these solar cells are composed of semiconducting materials (often silicon), and these cells receive solar energy and start The electrons are released from the semiconductor material or silicon to accumulate in the form of electrical energy, resulting in DC electricity (such as electricity produced chemically in batteries), which is then converted from DC electricity to DC. AC electricity, the electricity in our lives today, through a transformer called "Inverter" as shown in Figure 2.11.

Figure 2.11: Inverter

Types of solar cells

Although all solar panels work in the same way, there are several types of solar panels in the market, which differ among several variations to be identified to choose the right type of site (Green-Match, 2015), and the most common types of solar panels:

- Mono-crystalline, known as monocrystalline panels (Figure 2.12), is characterized by the purity of the silicon crystals from which the cells are made. The panels need to provide the same amount of electricity as other types, and also have the ability to work efficiently in low light, in addition to a high lifetime.

- Solar panel type (poly-crystalline): It is called polycrystalline solar panels (Figure 2.13), and different from the monotype in the form, where the cells are squares compact, and their efficiency is medium, which leads to the need for more of them to get the same electricity, which is less expensive than the monotype with high lifetime.
- The third type is called thin film solar panel (Figure 2.14). This type is flexible and easy to install. On the same amount of electrical energy that can be obtained from other species, as well as it has low lifetime.

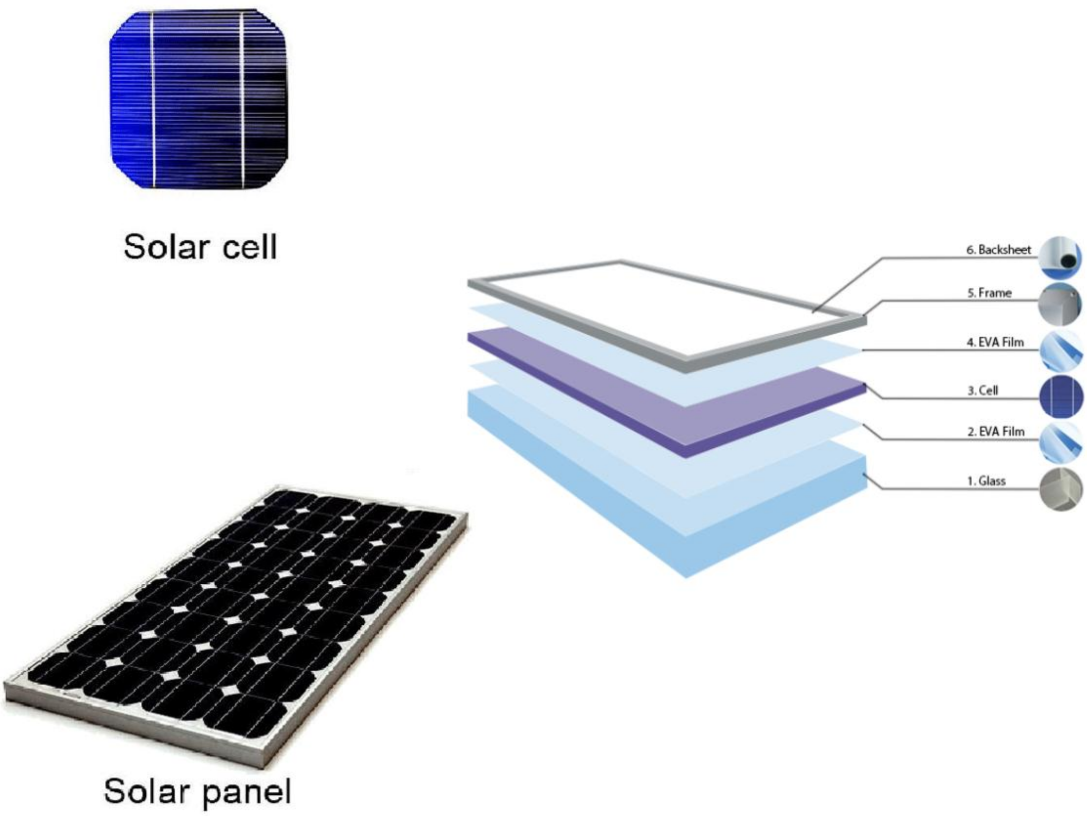

Figure 2.12: Monocrystalline solar panels

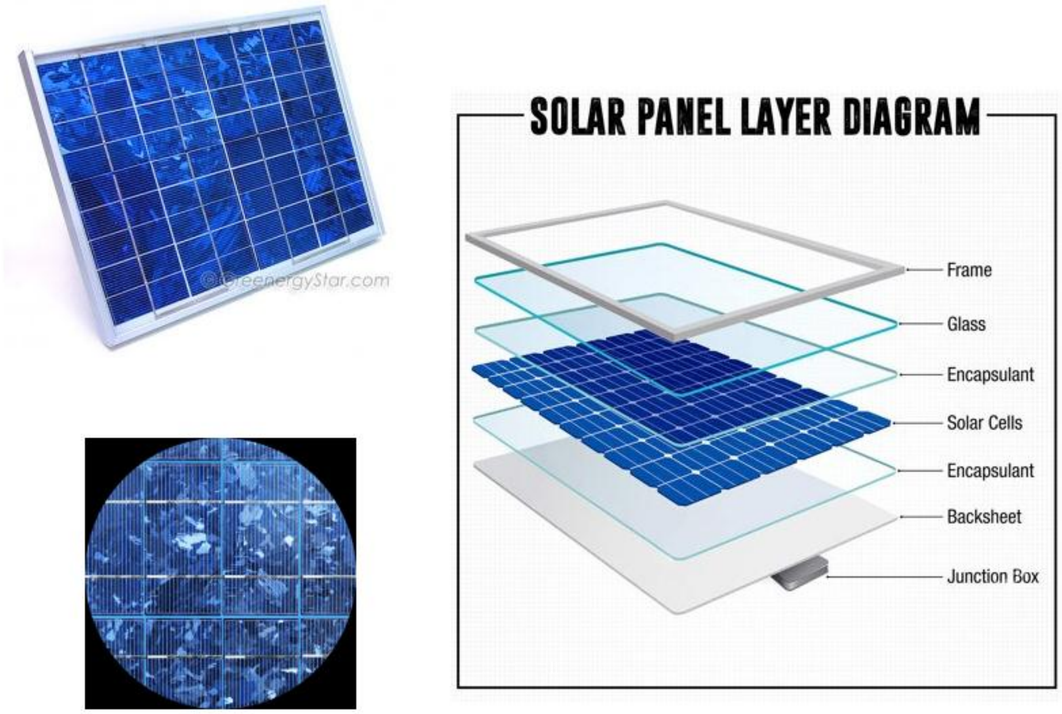

Figure 2.13: Polycrystalline solar panel

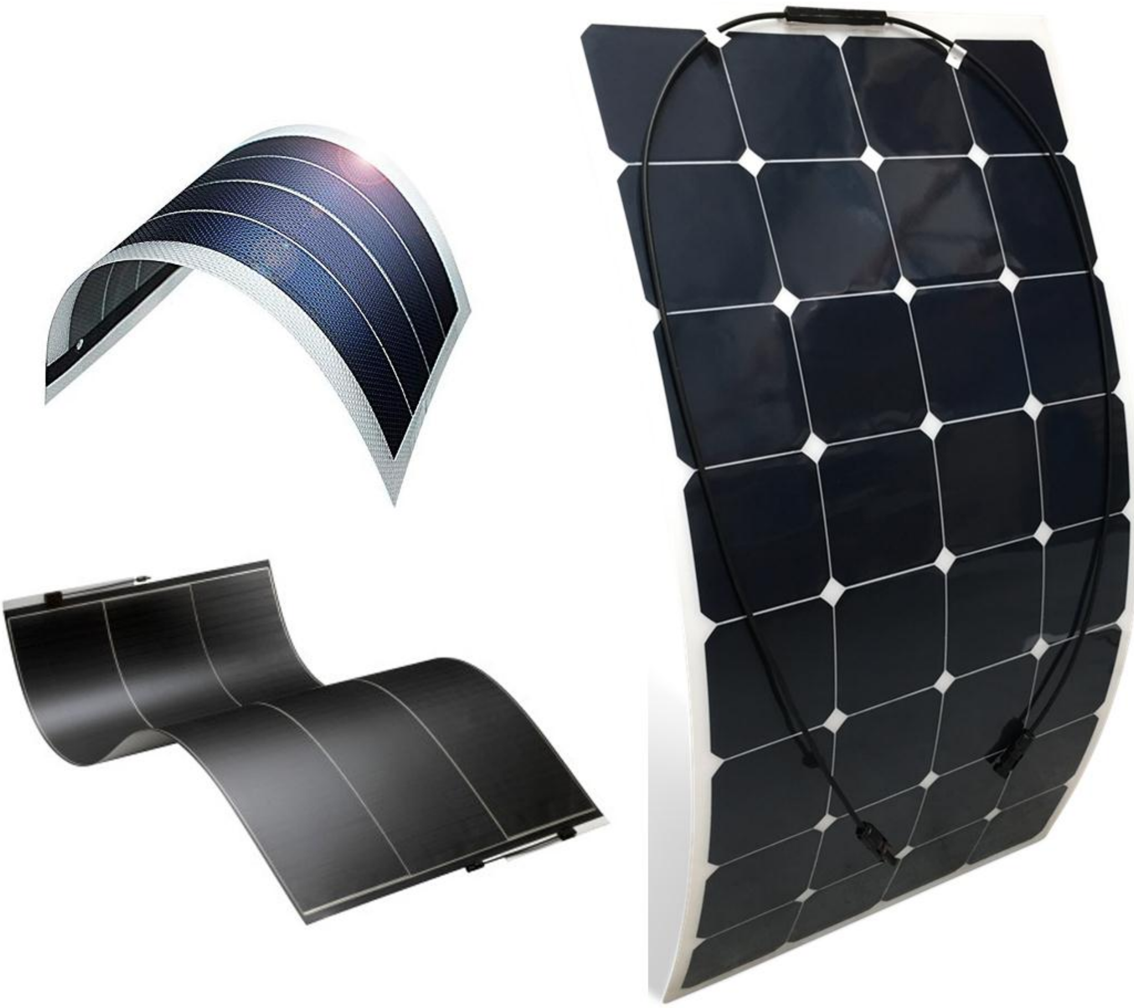

Figure 2.14: Thin film solar panel

2.3 Factors Affect the Solar Radiation Values

Solar radiation is the actual fuel for all solar energy systems, so the efficiency of solar panels producing electricity as well as thermal systems producing hot water depends on the availability and density of solar radiation. The radiation above the atmosphere is relatively constant, but the amount reaching the surface of the Earth varies very differently. In fact, there are many factors; however, the most important factors affecting the quality of solar radiation falling and thus the efficiency of the productivity of solar panels are (Krzyścin and Jarosławski, 1997)

Geographical presentation

Because of the spherical Earth, the rays falling on the surface are more intense and stronger as we get closer to the equator and because it is the shortest way of radiation to reach the surface perpendicular and thus the radiation lost due to collision with the atmosphere less. If we move away from the equator north or south, it will increase the period of fusion between radiation and the envelope, causing dispersion and thus weaken the intensity and strength of radiation.

Cloud coverage

Clouds are a significant factor relative to the amount of solar radiation falling on the surface because they reflect and absorb a large part of the sun's rays. Therefore, if there are two positions on one latitude, the difference in incident radiation may be significant depending on seasonal cloud coverage. In average, clouds absorb and reflect 20% of the total rays coming from the sun.

The suspended particles

Normally, the Earth's atmosphere has suspended particles of dust or products of human industrial activity and pollution, and the quantities and concentration of these bolds vary depending on the place and time of year. Its importance for solar radiation is that it filters and reduces radiation. While this affects the performance of solar panels, it is more detrimental to the performance of the radiation concentrates used in giant solar systems.

Height

The distance traveled by the radiation before reaching the surface of the Earth is less as the height of the Earth above sea level. Therefore, radiation loss rates are reduced and this results in better performance of all types of solar generators.

Shadow and angle

The place of installation and installation of solar panels is one of the most important things to consider if we are to absorb the maximum amount of incident radiation, considering that any shadows on solar panels or concentrates should be avoided by neighboring buildings or others during the daytime. An angle should be set for panels that meet the sun as much as possible throughout the day and often the ideal angle depends on your location for longitude, latitude and annual seasons.

CHAPTER 3
LEBANON

3.1 Energy Status in Lebanon

Lebanon is among the few countries in the world without electricity 24/24, and suffering from a large energy deficit. The energy production depends on fuel oil, diesel oil, and other imports, results in blackout periods of electricity are ranged from 4 to 14 h in all Lebanese regions and sometimes more. Currently, the electrical energy in Lebanon is generated by oil products, hydropower, and importation. The power plants in Lebanon are classified as thermal and hydroelectric. In fact, Lebanon has 13 power plants with a total capacity of 3016 MW distributed as 2764MW thermal plants and 252.6 MW hydropower plants. It concluded that above 97% of total energy is generated by thermal plants in 2015 and hydropower has a share of only 2.6% in 2015 as shown in Figure 3.1.

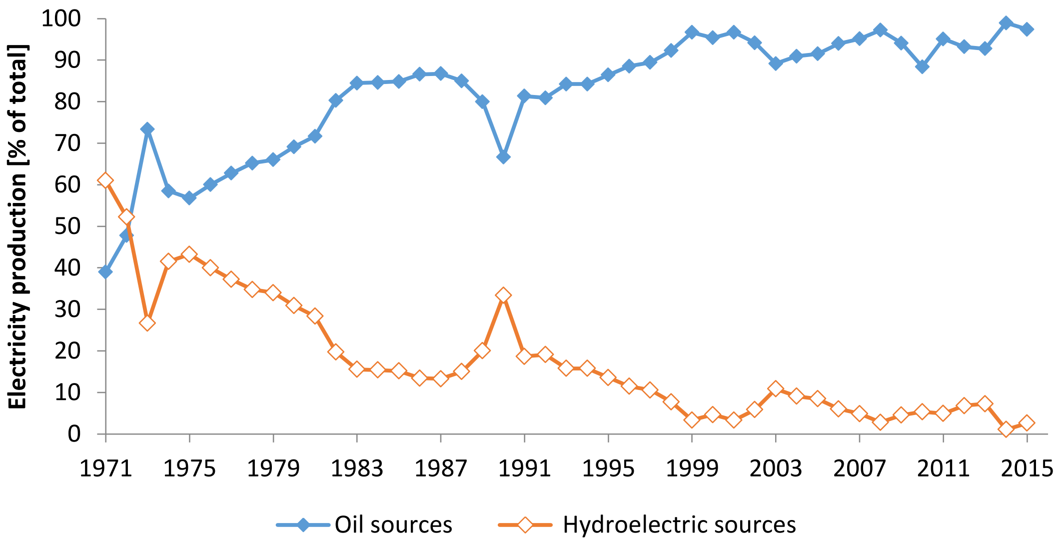

Figure 3.1. Electricity production from oil and hydroelectrically sources

The electricity crisis is one of the most issues affect the daily lives of citizens, shop owners, and small business activities that have been at the forefront of Lebanon for years. Lebanon is experiencing a real crisis because of the power cuts that continue for the long years in a row without proven solutions. The electricity service is getting worse in Lebanon. According to Lebanon News, the number of hours of interruption of the electricity in all cities of the country is increased day by day. Lebanon is not a country isolated from the world and the electricity sector crisis cannot be separated from the conditions of the global economy. International oil prices play a major role in increasing the deficit in the EDL. The higher the price of oil globally, the more the EDL losses will increase because it depends on 85% energy production on this oil. In addition, the causes of the crisis in the electrical sector in Lebanon are no alternatives to petroleum and low production capacity (the Electricity Corporation produces 1500 megawatts, while the demand reaches three thousand megawatts, which requires the construction of new factories). The current electricity tariff in Lebanon is among the highest tariffs in the Middle East region as shown in Table S1 as supplementary material. Therefore, the increases in populations and energy demand have increased in recent years the significance of renewable energy as an alternative source.

Currently, special diesel generators (DG) distributed throughout the country is used to meet the energy consumption needs of the population. During periods of power outages, the central public directorates in each region take responsibility and provide users with electrical energy. Subscriptions vary according to the needs of each consumer. While the majority of apartments may settle for the cheapest offer: general managers provide 1.1 kVA, and other citizens residing in larger homes with a higher standard of living tend to subscribe to more expensive offers that offer 2.2-4.4 kVA. The resulting fees increase in proportion to the subscription. It is worth noting that most of the time; executives are managed by non-professional individuals. Usually, no qualified engineers and technicians are consulted in the installation and commissioning processes that often lead to defects and damage to the requirements of home appliances and permanent maintenance along with poor electrical current quality and lower energy benefits than promised. On the other hand, industries, hospitals, offices, and centers tend to install their own generators according to their energy consumption. This solution provides complete control over electricity production during a power outage and helps reduce the fees generated, or at least the ability to manage them. Installing DGs is an alternative solution that not only causes massive air pollution, but is very uncomfortable due to the industry's medium regulation. Moreover, it does not provide flexibility to the user, meaning that a fixed amount of money is imposed on the population independently of the amount of energy consumed. The resulting fees are highly influenced by fuel prices and blackout hours. Recently, Lebanese municipalities began publishing a fixed monthly tariff for each subscription in order to try to contain chaos and price differentials between different regions of the country.

3.2 Renewable Energy Potential in Lebanon

Lebanon is located on the Mediterranean Sea with a surface area of 10452 km^2 and a coastline of 220km. The number of population in the country is estimated at 4 million. As the Lebanese electricity system is mainly based on thermal energy, tons of dangerous gases are emitted in the atmosphere every single day. According to Chedid et al. (2001) the energy sector in Lebanon was found to contribute 85% of all CO_2 emissions and 96% of all SO_2 emissions. Therefore, renewable energy projects are reflected in a worldwide decrease in CO_2 levels in several countries. Renewable energies are offered by natural sources that are persistently and sustainably replenished. In general, PV, wind and hydropower are the most interested resources to explore in Lebanon.

As mentioned previously, around 2% of the total energy is produced by hydropower stations. Hydropower is the unique renewable source used in electricity generation, although Lebanon has the potential to benefit from other resources, especially solar and wind. According to the United Nations Development Program (UNDP), the wind potential is estimated to be 1500MW in Lebanon. Moreover, according to Abdeladim et al. (2018), Lebanon has a high amount of sunny hour and the daily average solar insolation is about 4.8kWh/m^2. Numerous studies have been investigated the potential of renewable energy in terms of solar energy and wind energy in Lebanon.

For an instant, Al Zohbi et al. (2015) investigated the characteristics of wind speed of five locations in Lebanon. They found that wind power could reduce the electricity demand in Lebanon.

Zohbi et al. (2016) evaluated the performance of a hybrid wind-hydro power plant, in two dams in Lebanon in order to find the best dam to generate energy by wind power at night. The authors concluded that the combination of wind energy with a pumped hydro storage system could be a vital solution to solve Lebanon's electricity crisis.

Kassem et al. (2019) investigated the wind potential in three coastal regions (Beirut, Sidon, and Tripoli) in Lebanon. The authors found that vertical axis wind turbines offer the potential to outperform horizontal axis wind turbines in urban environments.

Gökçekuş et al. (2019) analyzed the wind speed characteristics and wind energy potential at eight selected locations in Northern Lebanon. They concluded that small-scale wind turbine use can be suitable for generating electricity in the studied regions.

Kassem et al. (2019) investigated the wind potential at some selected regions in Lebanon using the Two-Parameter Weibull distribution function. The results indicated that the wind speeds at the selected regions are within the range of 2.627 m/s and 3.56 m/s. Furthermore, the wind speed densities are varied between 14.634W/m^2 and 25.280W/m^2, which classified as poor wind power.

Tannous et al. (2018) investigated and compared traditional grid-connected systems and solar stand-alone system for two street lighting technologies in Lebanon. The results showed that the solar system has less overall environmental impacts than the traditional system.

Ibarra-Berastegi et al. (2019) evaluated Lebanese offshore-wind-energy potential. They found that wind power density along the shore, with the northern coastal area exhibiting the highest potential and reaching winter values of around 400 W/m2.

Elkhoury et al. (2010) investigated the feasibility of wind turbines farms for generating electricity in four sites in Lebanon. The results indicated that Zahleh and Beirut could be good candidates in terms of wind energy harvesting in Lebanon due to their relatively high wind speeds.

CHAPTER 4
MATERIAL AND METHOD

4.1 Solar Photovoltaic System

It is a system made up of solar cells, also called photovoltaic that takes advantage of sunlight and transforms through photovoltaic processes for electrical energy. The solar PV system uses PV modules to convert sunlight into electricity. The components of solar PV system are discussed in this section. The stand-alone PV systems and connected PV systems (off-grid PV systems) are the most commonly used variations of the solar PV system. Solar charge controller, battery bank, solar panel, auxiliary energy, loads and inverter are the main components of the solar PV system. The characteristics of these components depend on the location of the site and applications.

Solar panel

It is known to be the first element of all solar energy systems. It's being used to convert solar energy into direct electricity with an average life expectancy of between 20 and 30 years. Due to fast technological development, the prices for a PV system is decreased and the PV cell technologies can be categorized based on materials used such as polycrystalline silicon, cadmium telluride (CdTe), monocrystalline silicon, amorphous silicon polymer & organic PV, and), copper indium gallium selenide (CIGS). In general, monocrystalline silicon modules are commonly used in large-scale PV system. Additionally, they are cheaper to produce than other PV cell technologies because of the simpler manufacturing process required.

Solar charge controller

The Solar Charge Controller, or Solar Charge regulator, is an important device for almost all solar energy systems that use batteries as a chemical energy storage solution. It can be used in hybrid solar or stand-alone systems, but can’t be used in systems connected directly to the network that do not contain rechargeable batteries. They are used in most PV systems to protect the battery from overcharging. Overcharging may cause the electrolyte to vaporize the battery, causing a malfunction, and excessive battery discharge may lead to premature battery failure.

Solar battery

It is expected to be the second major component of the off-grid solar PV system because it is used to reserve electricity generated by solar panels. Its importance lies in storing electricity for use at sunset and evening. Additionally, the 2VDC nominal voltage lead acid battery is widely used for off-grid solar PV due to its durability as a result of non-leakage of the electrolyte from the terminal of the battery.

Solar inverter

It's a type of electrical equipment that converts the DC current generated from solar panels to alternating current that can be fed to the electrical grid or used locally to supply the electrical load separate from the grid. Solar inverters are considered to be an important component of the stability of solar electric systems, as electrical loads that run on the AC system are allowed to run, and it also has an important role in protecting against the phenomenon of fragmentation in solar panel systems connected to the electrical network, and another role in tracking the maximum power point.

4.2. Design Parameters for a Photovoltaic Solar System

In this section, the methodology that is considered for the proposed solar PV plants in Lebanon is discussed. The methodology considered for the proposed solar PV plants in Lebanon is discussed in this section. Generally speaking, inverter sizing the battery sizing and PV module sizing are important parameters for designing solar PV plant. In the present study, 12kW grid-connected rooftop PV plant is proposed for generating enough energy to power the residential and commercial building in coastal cities in Lebanon. The number of households in the selected cities is shown in Figure 4.1. Based on the number of building in the locations, it can be concluded that the total capacity of PV solar plants is 1.2GW. It should be acknowledged that solar angle, solar monitoring, shading or partial shade, dust and cell operating temperature are the most significant factors affecting the power generation of the PV system (Hosenuzzaman et al., 2018). In addition, the capacity for using solar energy in urban areas is highly dependent on the urban morphology that affects the amount of solar irradiance obtained by individual buildings (Lau et al., 2017).

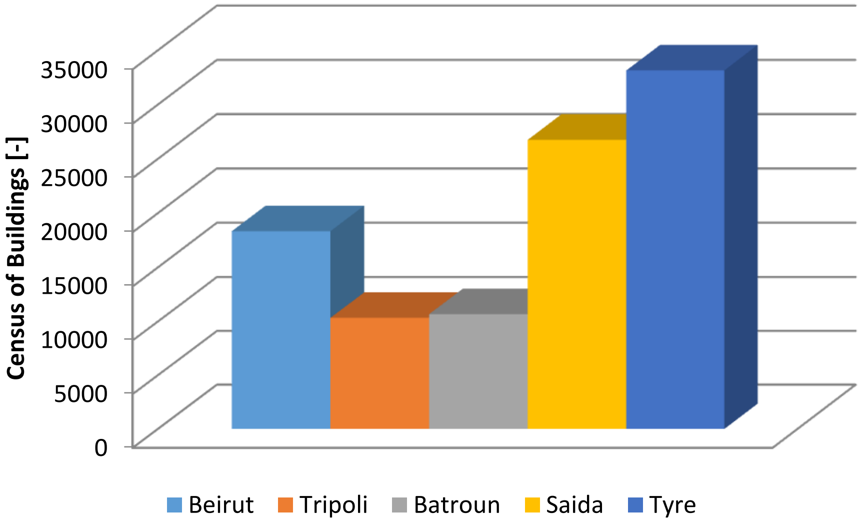

Figure 4.1 Number of building in each selected region

Power generating factor

The power generation factor (PGF) is an important aspect in the measurement of solar photovoltaic technology based on the system's total Watt peak rating. The PGF is calculated by using the equation below.

$$PGE = \frac{Solar\ irradiance \times Sunshine\ hours}{Standard\ test\ condition\ irradiance} \tag{4.1}$$

Energy demand

The total energy and power consumption of all loads to be supplied by the chosen location system are essential factors for the design of the solar PV system.

Solar PV energy required

The energy to be provided by the PV module is the total Watt-hour / day needed by the PV modules and is calculated using Eq. (4.2).

$$\begin{aligned} &\mathit{The\ energy\ required\ from\ PV\ modules} \\ &\qquad = \mathit{Peak\ energy\ requirement} \\ &\qquad \times \mathit{Energy\ lost\ in\ the\ system} \end{aligned} \tag{4.2}$$

PV module sizing

In order to calculate the size of the photovoltaic modules required, it is first necessary to estimate the total Watt-peak rating needed for the PV modules using equations (4.3) and (4.4).

$$\mathit{Total\ Watt\ peak\ rating} = \frac{\mathit{Solar\ PV\ energy\ required}}{\mathit{panel\ generation\ factor}} \tag{4.3}$$

$$\mathit{PV\ module\ size} = \frac{\mathit{Total\ Watt\ peak\ rating}}{\mathit{PV\ output\ \ power\ rating}} \tag{4.4}$$

For the proposed 12kW grid-connected solar PV system, the mono-Si-SF160-24-1M170 module produced by Hanwha Solar One is selected as an efficient PV module currently available on the market. The area of these modules is calculated to be approximately 100m2. The specification of the module used is shown in Table 4.1. In addition, 71 of the module chosen, which is calculated using Eq. (4.4), are necessary for the construction of the proposed device.

Table 4.1: Main specifications of the selected PV modules

Electrical Characteristics at Standard Test Conditions (STC)[a]	
Maximum Power, $P_{max,}$ [W]	170
Open Circuit Voltage, V_{oc} [V]	43.8
Short Circuit Current, I_{sc} [A]	5.36
Voltage at Maximum Power, V_{mpp} [V]	35.0
Current at Maximum Power, I_{mpp} [A]	4.86
Module Efficiency [%]	13.3
Cell Efficiency [%]	15.4
Electrical Characteristics at Normal Operating Cell Temperature (NOCT)[b]	
Maximum Power [W]	122
Open Circuit Voltage [V]	40.3
Short Circuit Current [A]	4.37
Voltage at Maximum Power [V]	31.5
Current at Maximum Power [A]	3.89
Module Efficiency [%]	11.9
Cell Efficiency [%]	15.4
Mechanical Characteristics	
Dimensions [mm]	1580 × 808 × 40
Weight [kg]	14
Cell Technology	Monocrystalline
Cell Size [mm]	125 × 125
Number of Cells (Pieces)	72 (6 × 12)
Output Cables	Solar cable: 4 mm^2; length 900 mm
Connector	Linyang LY0706–2
Operation Conditions	
Normal Operating Cell Temperature (NOCT)	45 °C ± 3 °C
Temperature Coefficients of P	– 0.44 % / °C
Temperature Coefficients of V	– 0.33 % / °C
Temperature Coefficients of I	+ 0.03 % / °C

[a] P_{max}, V_{oc}, I_{sc}, V_{mpp}, and I_{mpp} tested at STC defined as irradiance of 1000 W/m2 at AM 1.5 solar spectrum and temperature 25 ± 2 °C.

b P_{max}, V_{oc}, I_{sc}, V_{mpp}, and I_{mpp} tested at NOCT defined as irradiance of 800 W/m^2; wind speed 1 m/s.

Inverter sizing

The size of the inverter used for any solar photovoltaic project depends on the total amount of energy required and the safety factor, and is determined as shown below.

$$Inverter\ size = Peak\ energy\ requirement \times Factor\ of\ safety \tag{4.5}$$

- Peak energy requirement = 12kW

- Factor of safety = 1.3 [26]
- Inverter size = 12 × 1.3 = 15.6kW

In this study, two StecaGrid 8000 + 3ph grid-connected inverter units are used for the developed solar PV system with a total capacity of 16 kW. The specification of the inverter used is shown in Table 4.2.

Table 4.2. Grid-connected inverter specifications

DC side (PV generator connection)	
Maximum input voltage [V]	845
Rated input voltage [V]	(350–600)
AC output side (mains grid connection)	
Rated output voltage [V]	380
Rated output current [A]	11.6
Rated output power [W]	8000
Max. apparent power [VA]	9780
Grid frequency [Hz]	47.5–52
Power factor [-]	0.90
Maximum efficiency [%]	96.3

4.3 Economic Model

Scientists, researchers, and engineers have used various simulation tools to estimate the annual and monthly energy generation and the capacity factor of the installed solar PV system. Numerous scientific researchers have used RETScreen and other related software such as HOMER to evaluate the technological and environmental sustainability of solar PV technology worldwide (Kassem eta l., 2020).

RETScreen Expert software is used to analyze the techno-economic and environmental aspects of the 12kW grid-connected rooftop solar PV system and to compare its capacity between selected cities. RETScreen software is a useful tool for analyzing and evaluating the feasibility of a grid-connected renewable energy system. Based on input data, RETScreen software is able to estimate annual and monthly energy generation, capacity factors and other significant economic measures. In addition, a feasibility study is used to assess the viability of the project in order to ensure that the project is both legally and technologically viable and economically justifiable. The financial parameters for the proposed systems which appear to be economically feasible are set out in Table 4.3. In addition, Figure 4.2 outlines the methodology used by RETScreen Expert software

Table 4.3: Economic parameters used for analysis

Parameter	Unit	Value
Initial costs		
PV module	\$/kWp	2.90
Lifetime of PV module	Year	25
Cost of each unit of inverter	\$	≈ 1900 dollar
Total Initial Cost	\$	29472
Periodic Cost Items		
Operations and Maintenance cost	\$/year	0
Financial parameters		
Inflation rate	%	2.7
Discount rate	%	10 [32]
Electricity export escalation rate	%	5
Debt ratio	%	50
Debt interest rate	%	0
Debt term	%	20

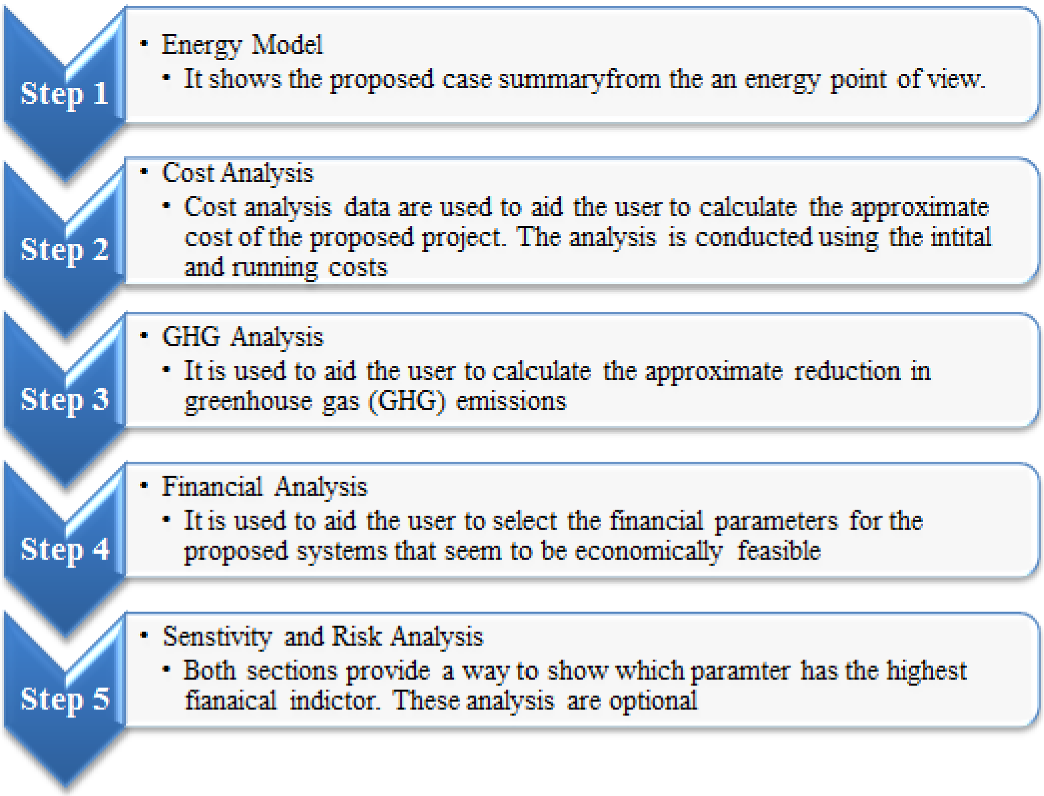

Figure 4.2: Standard analysis in RETScreen software

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Global Solar Resources in Lebanon

Lebanon must make big decisions on its energy infrastructure, especially in the power sector, in the coming years. Lebanon also has an immense amount of solar energy generation. In general , two descriptive parameters, namely global horizontal irradiation (GHI) and direct normal irradiation (DNI), are used to measure the country 's global solar resources. GHI and DNI are considered to be essential criteria for the assessment of the energy production of PV / flat-plate photovoltaic technologies and the development of CSP (concentrating solar power) and CPV (concentrating photovoltaic) systems. Depending on the global solar atlas map, Lebanon's annual average GHI ranges from 1680 kWh / m2 to 2118 kWh / m2 (see Table 5.1).

Table 5.1. Low voltage EDL Electricity Tariffs in cent/ kWh

Tranche	kWh level	LBP	US Cent
1^{st}	0-100	35	2.3
2^{nd}	100-300	55	3.7
3^{rd}	300-400	80	5.3
4^{th}	400-500	120	8
5^{th}	>500	200	13.3
Public		140	9.3
Administration, handicraft and agriculture		115	7.7

The maximum global horizontal irradiation is in the western part of Lebanon, which ranged from 5.4 to 5.8 kWh / m2 / day as shown in Figure 5.1. It is also noted that the annual DNI values for the western part of Lebanon are within the range of 6.4-7.2 kWh / m2 / day as shown in Figure 5.2. These results indicate Lebanon has huge solar energy for assessing energy generation for PV/flat-plate photovoltaic, CSP and CPV technologies. In addition, air temperature (TEMP) is considered to be the second significant parameter for determining the efficiency of the solar PV system. Air temperature values are found to range from 5.3 ° C to 21.9 ° C, as shown in Figure 5.3. It can be concluded that Lebanon has huge solar potential and it can be used to generate power, i.e., the PV output power is within the range of 3.99-5.30 kWh/kWp as shown in Figure 5.4. as supplementary material.

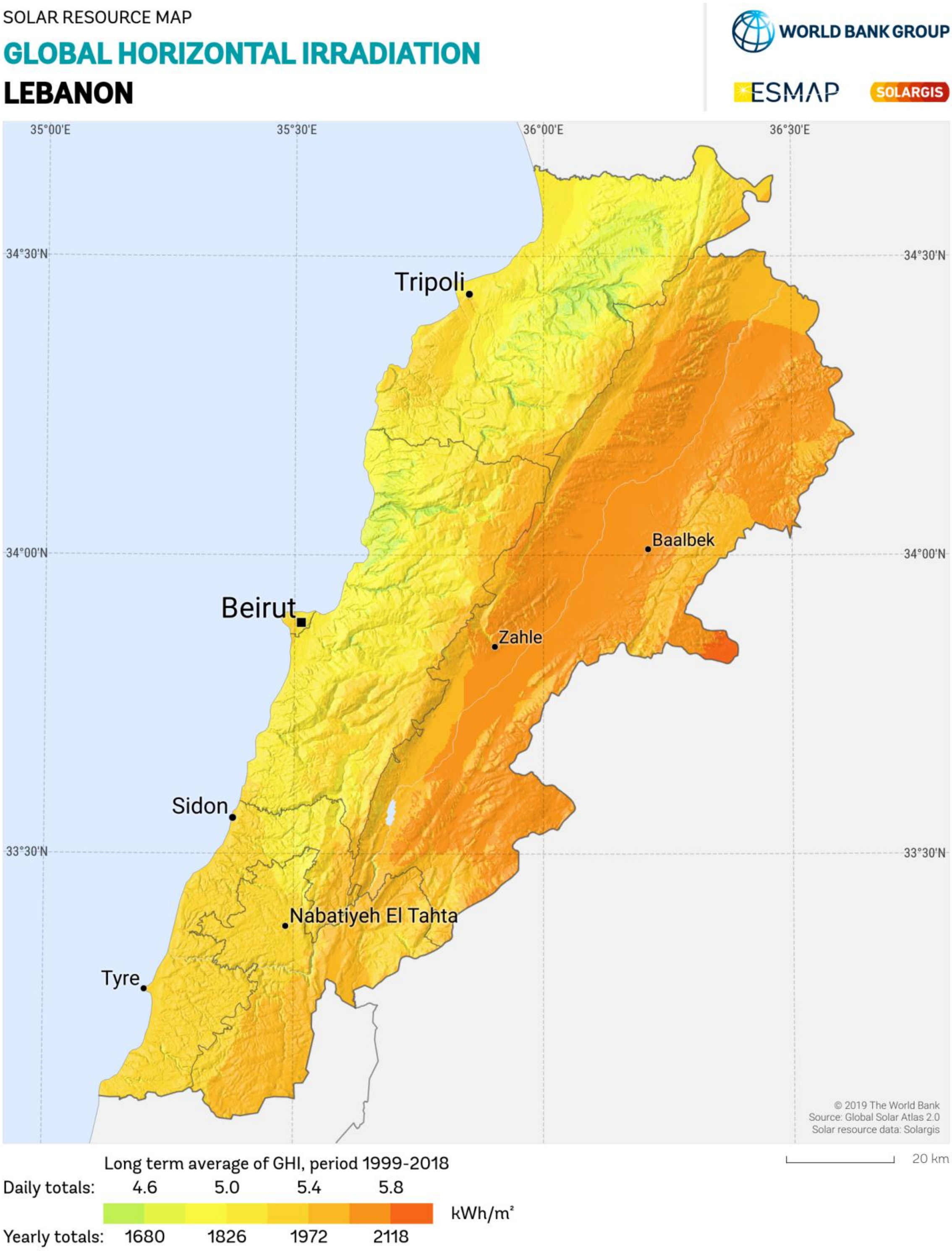

Figure 5.1: Long-term averages of GHI of Lebanon

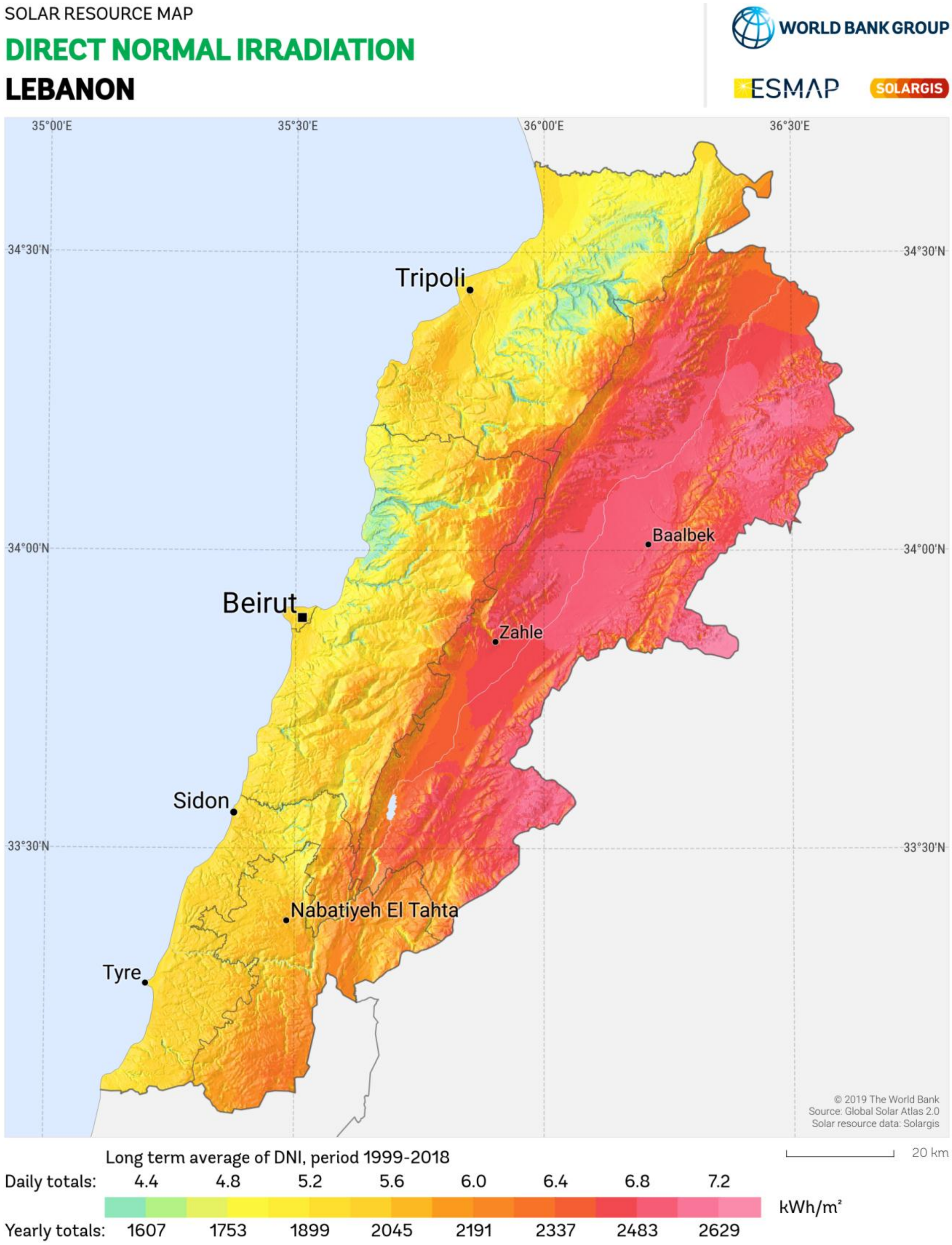

Figure 5.2: Long-term averages of DNI of Lebanon

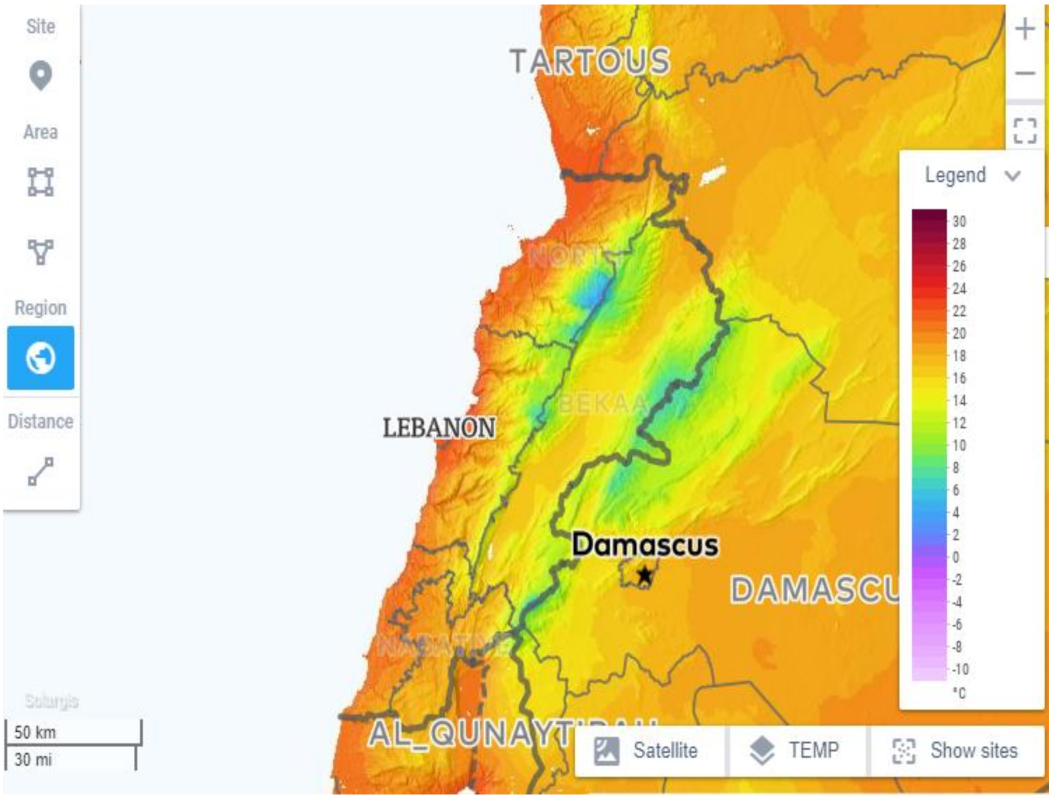

Figure 5.3. Long-term averages of air temperature in Lebanon

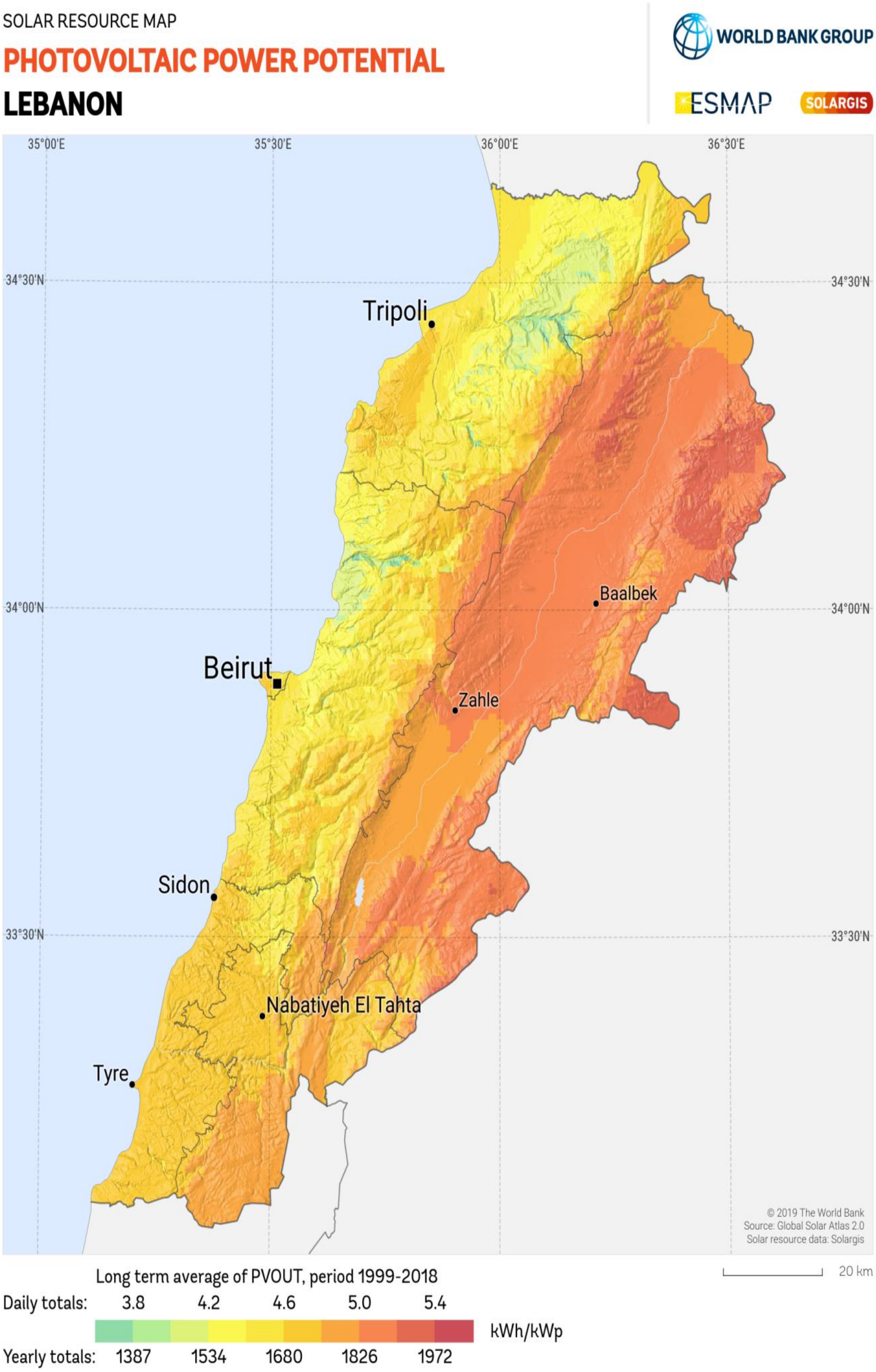

Figure 5.4. Long-term averages of PV output of Lebanon

Generally, the global solar atlas map is the most accurate data source available at the moment which is used to estimate the solar potential in a particular area. It is good enough for the first step for decision making about proposing a solar PV project in the country. In addition, at the stage of the creation of the solar PV project, meteorological data are needed for financing, engineering, technological design, due diligence and risk assessment.

5.2 Solar Radiation and Air Temperatures

NASA 's global solar data were used in this analysis to determine the solar capacity of five selected coastal cities in Lebanon. The monthly variations of GHI and TEMP for all selected cities in Lebanon are shown in Figure 5.5-5.9 Depending on the results, the GHI values range from 4.66 kWh / m2 / day to 5.50 kWh / m2 / day. The maximum annual GHI values are recorded in Batroun and Tripoli and the lowest value are recorded in Beirut and Sidon. Furthermore, it is found that the highest annual value of GHI of 65.92kWh/m^2/day is achieved in Batroun and Tripoli. Additionally, it is noticed that the maximum and minimum value of air temperature is recorded in Tyre and Batroun and Tripoli with a value of 20.65 ℃ and 18.60℃, respectively. Moreover, it is observed that the maximum value of GHI and TEMP is obtained in June and August, respectively.

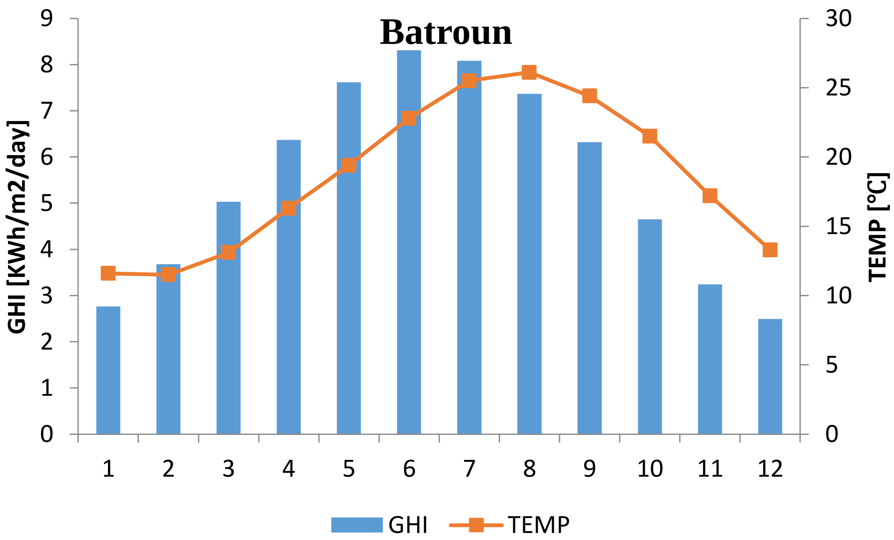

Figure 5.5: Average monthly GHI and TEMP in Batroun

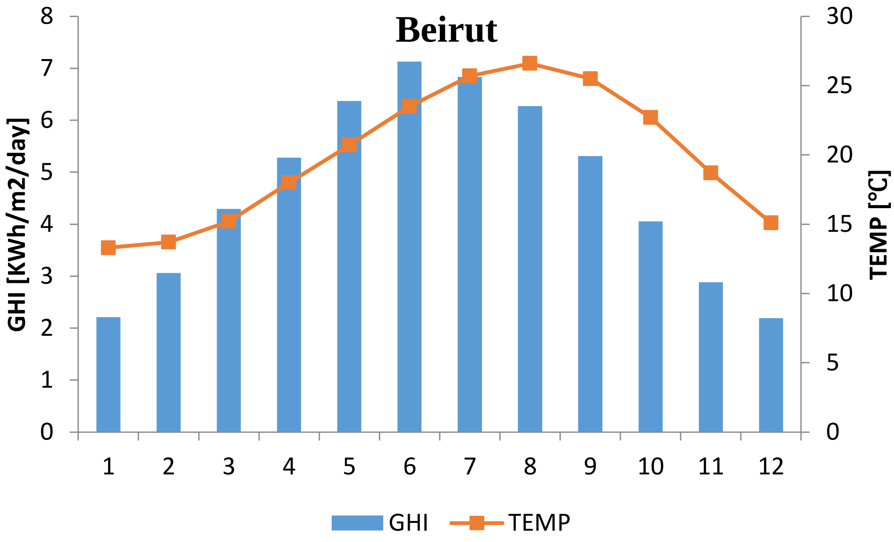

Figure 5.6: Average monthly GHI and TEMP in Beirut

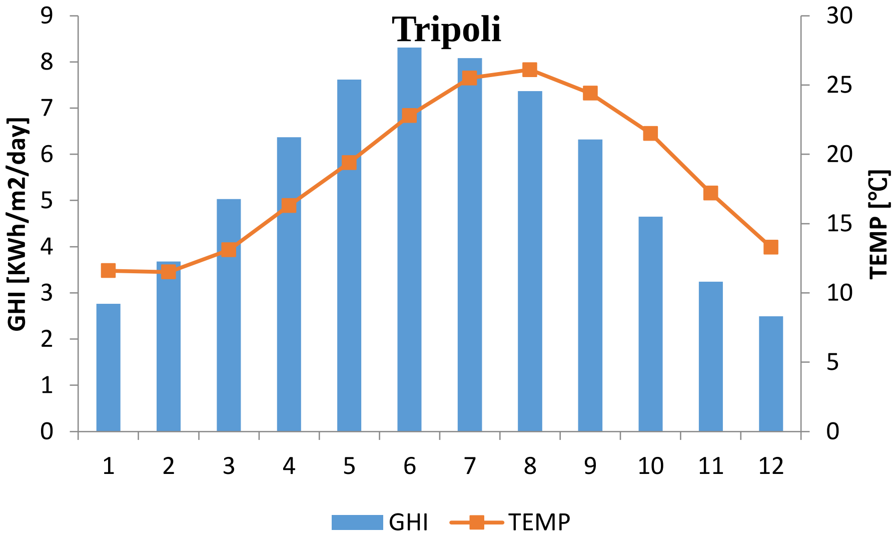

Figure 5.7: Average monthly GHI and TEMP in Tripoli

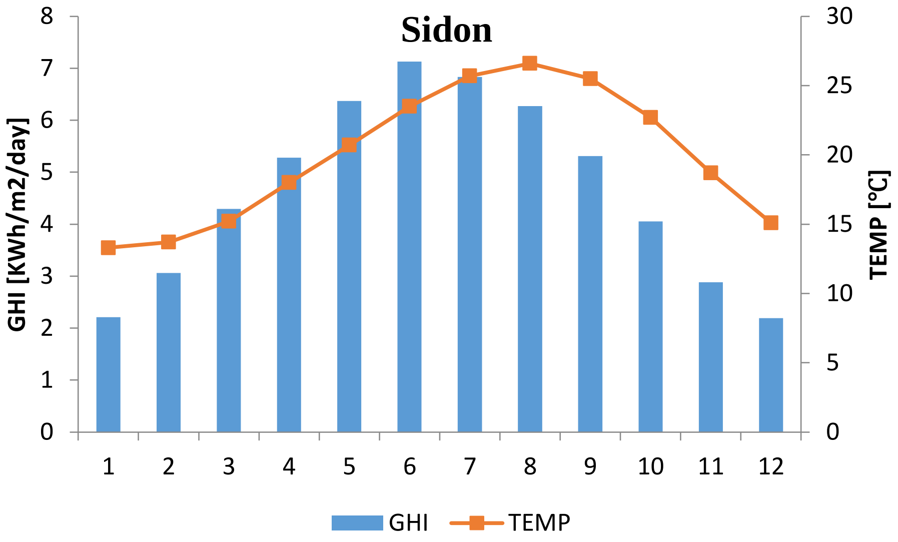

Figure 5.8: Average monthly GHI and TEMP in Sidon

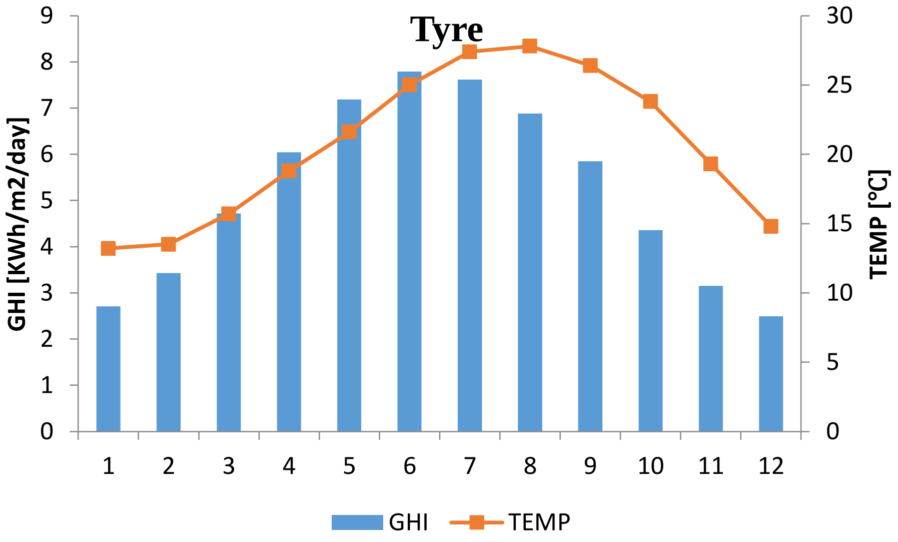

Figure 5.9: Average monthly GHI and TEMP in Tyre

5.3 Technical Viability

In this research, a fixed-tilt system is considered for a rooftop solar PV system in all selected cities. The purpose of this section is to show how much solar energy can be absorbed by the surfaces of the building, which may be helpful, particularly when PV systems are used in the building in the form of solar panels to turn sunlight into electricity. The slope and azimuth angles for the device therefore range from 40 ° to 20 ° and from 5 ° to-5 ° respectively. The optimal slope and azimuth angles for each city are shown in Table 5.2. Such angles are chosen on the basis of the average value of the solar irradiance and the energy transmitted to the grid for each position obtained with each sloping and azimuth angle.

Table 5.2: Optimum slope and azimuth angle for five cities in Lebanon

Angle	**Batroun**	**Beirut**	**Tripoli**	**Sidon**	**Tyre**
Slope angle [°]	30	29	29	28	29
Azimuth angle [°]	-3	-2	-2	0	3

Generally, the PV production depends on the position of the solar radiation and the amount of clear sunny days influencing the annual energy supplied to the grid and the capacity factor of the system. The monthly variability of the average energy supplied to the grid of selected cities is shown in Figure 5.10, based on the optimum angles. In addition, the yearly energy exported to the grid ranged between a minimum of 19,684MWh in the city of Beirut and a maximum of 23,765MWh in the city of Tripoli, impacting the annual electricity exported from the cities (see Figure 5.11). According to the results of Ref. (Owolabi et al., 2019; Rehman et al., 2017), the results of the yearly energy exports to the grid and the capacity factor of each city in Lebanon are consistent with the appropriate values and are thus economically feasible in the development and operation of solar photovoltaic plants in the five cities on the basis of the technological viability of the solar system.

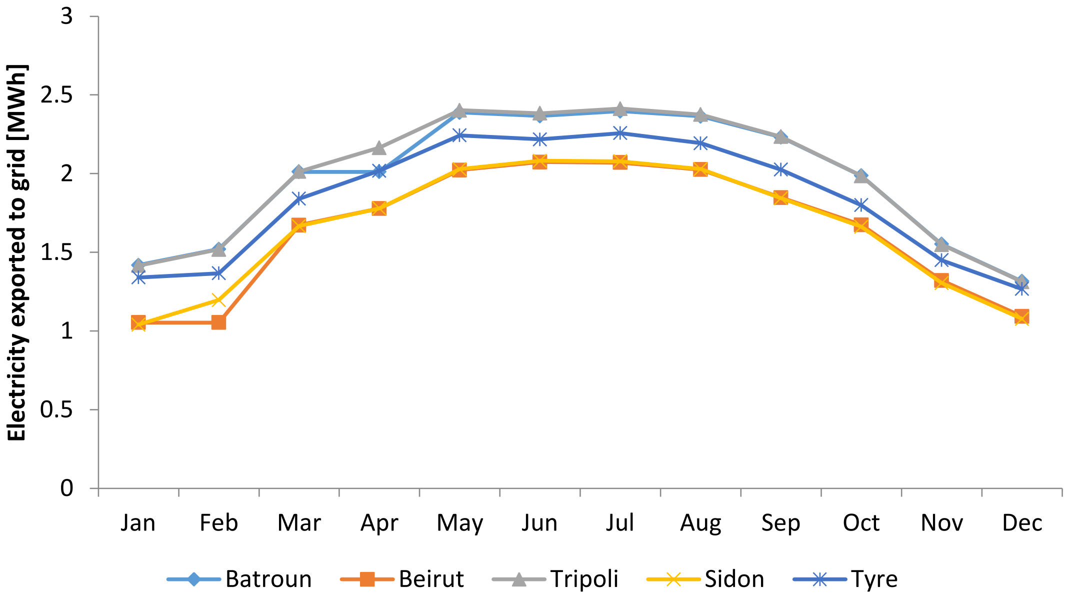

Figure 5.10: Monthly variation of the generating electricity

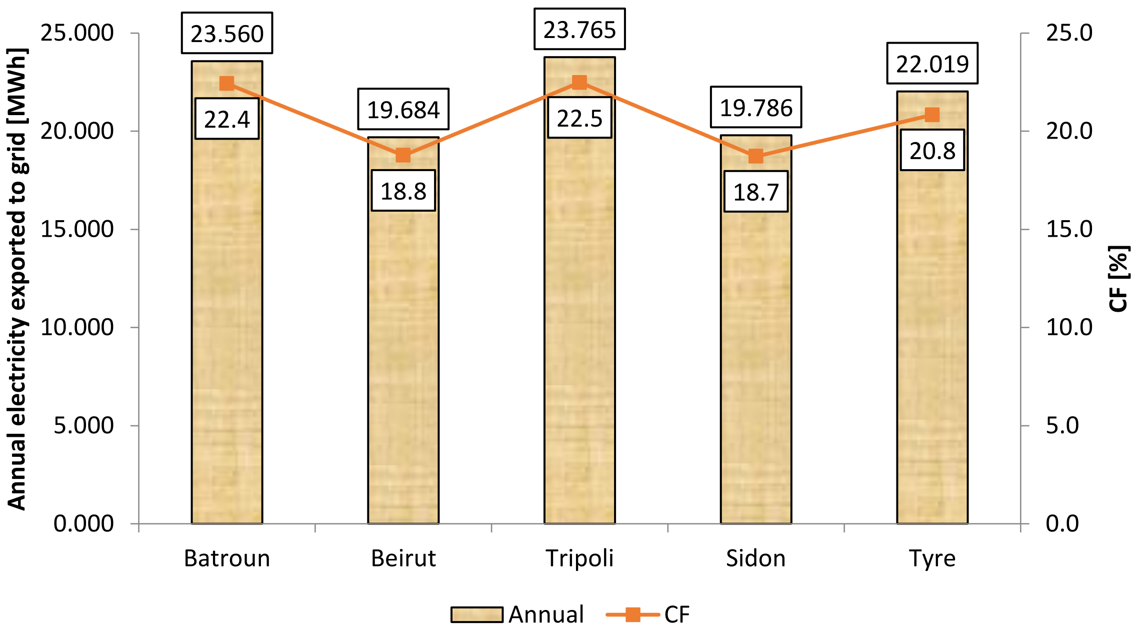

Figure 5.11: Solar photovoltaic energy summary for all cities

5.4 Economic sustainability and emission reduction assessment

Economic analysis is an important study to assess whether the project is economically feasible and sustainable. Studying the economic feasibility of the PV power plant supports and advises both investors and policy-makers. The financial analysis of the RETScreen program involves other financial parameters, such as discount rate, inflation rate, debt ratio, reinvestment rate, debt interest rate as input variables.

Based on the input variables, Internal Rate of Return, Modified Internal Rate of Return (IRR), Simple payback, Equity payback, Net Present Value (NPV), Annual life cycle savings, Debt service coverage, Benefit-Cost (B-C) ratio, GHG reduction cost, levelized Cost of Electricity by the RETScreen software as shown in Table 5.3. According to Ref. (Rehman et al., 2017; Rashwan et al., 2017; Otuagoma et al,, 2013) NPV, IRR and the payback period are the key economic viability factor for the calculation of the PV project. According to the analysis, the NPV values for all cities are positive, indicating that the project proposal is considered to be economically and financially according (Rehman et al., 2017; Rashwan et al., 2017; Otuagoma et al,, 2013).

Additionally, the value of the IRR used to calculate the profitability of the project is higher than the acceptable rate of return of the project [10, 32]. This tends to make solar PV projects in selected cities economically optimal when considering the required rate of return of the project at the discount rate. Furthermore, the easy payback period, which is the amount of time required to recover the initial expenditure of the project at six locations, is shown in Table 5.

The planned PV project in Sidon City now has longest payback period of 14.90 years , followed by the one in Beirut City of 14.86 years, while Tripoli City has the shortest payback period of 12.40 years. In comparison, Beirut has the highest Equity Refund of 8.32 years, while Tripoli has the lowest Equity Refund of 6.84 years. In addition, it is observed that Tripoli has the lowest electricity cost of $0.0974 / kWh followed by Batroun with a value of $0.0976 / kWh, whereas Beirut has the highest electricity cost of $0.1167 / kWh.

The Emission Analysis Worksheet is used to measure the reduction of greenhouse gas (GHG) emissions resulting from the deployment of solar PV. The algorithm estimates the total annual reduction of GHG emissions for each of the five cities as shown in Table 5. The plan in Tripoli has a gross GHG emission reduction of 16,80 tCO2 and a gross GHG emission reduction of 87,210$/tCO2. This is followed by the Batroun state project and the least pollution reduction resulting from the Sidon city project.

Table 5.3: Financial output variables from the RETScreen Expert

Financial viability	Batroun	Beirut	Tripoli	Sidon	Tyre
Internal Rate of Return – assets [%]	9.5	7.5	9.52	7.77	8.95
Simple payback [%]	12.43	14.86	12.40	14.90	13.38
Equity payback [%]	6.86	8.32	6.84	7.83	7.01
Net Present Value (NPV) [$]	13214.81	7625.30	13299.38	8477.85	11701.17
Annual life cycle savings [$/year]	1455.80	840.10	1465.16	933.98	1289.09
Benefit-Cost (B-C) ratio	1.9	1.5	1.9	1.5	1.8
GHG reduction cost [$/t$CO_2$]	86.870	59.911	87.210	66.773	80.582
Levelized Cost Of Electricity [$/kWh]	0.0976	0.1167	0.0974	0.1118	0.1005
Gross annual GHG emission reduction [tCO_2]	16.76	14.02	16.80	13.99	16.00

5.4 Successful policies for supportting solar PV power system

Sustainable energy policies are distinctive to the country's geography, technological and financial capacity, population density and sovereignty obligations that regulate the deployment and production of its renewable energy sources. Numerous policy recommendations and interventions are required in order to develop and promote renewable technologies, in particular solar PV technology in the country. Generally speaking, a good renewable policy or market requires five measures that make up the policy design process, and these are

- Defining the targets for renewable energy sources
- Identifying the appropriate strategy for achieving the objectives

- Implementation of the plan
- Monitoring and enforcement
- Compliance evaluation

In addition, successful renewable policies or markets depend on the technology-specific financial support provided by Haas et al., (2011). Though, there are a few obstacles to the use of renewable energy in developing countries in general and Lebanon in precise, which fall under political, financial, institutional and technological constraints. Financial and economic constraints are considered to be one of the main factors influencing the use of renewable energy technologies as power generation in developing countries. These restrictions are focused in the high capital cost of renewable energy projects with a lack (or absence) of financing mechanisms, in addition to the false assumption that investing in such projects causes a financial risk despite being environmentally friendly. In addition, some banks and sources of funding do not promote loans and investments in emerging industries relative to conventional energy ventures, and this supports the likelihood that investments in renewable energy may not be of clear in-kind value and may not be economically viable (cost-benefit analysis) compared to other investment opportunities. Government can therefore promote investment in new and renewable energy sectors.

Setting up environmentally-friendly policies, such as exempting or reducing energy production taxes from renewable and environmentally-friendly sources, and imposing taxes and fines on the most polluting sources.

- Providing financial aid and funding and receiving project loans that are targeted towards the use of renewable resources.
- Setting and implementing standards and regulations relating to new and renewable energy within the context of all parties concerned.
- Reconsidering petroleum products pricing systems and linking them to fuel quality

In addition to taking into account comprehensive project plans, which provide a description of the processes, frameworks and planned implementation program for the project, the evaluation of the technical requirements, strategies, resources and skills required for implementation, the calculation of the overall value of the expenditure and its terms and conditions, and the assessment of the direct and indirect financial benefits of the project Including the benefits of reducing dependence on fossil fuels and the environmental benefits of it.

In fact, public perception is defined as one of the limitations on the country's use of renewable energy sources. The lack of interest in using green energy sources for energy production and the lack of awareness of the essence of the research and implementation of renewable energy technology by the parties involved and by society at large is a significant barrier to relying on sustainable energy sources for energy production. This challenge reinforces the general feeling among organizations and individuals that, on the one hand, there is little value in environmental initiatives and the viability of using structures that rely on evolving natural phenomena (such as the sun and the wind). Here, the aspect of information and knowledge is evolving to move towards the rehabilitation of individuals and communities as a whole towards a correct definition of energy production from clean and environmentally sustainable sources, keeping in mind that knowledge is not limited to public media initiatives and encourages them to turn to new and renewable energy technologies only. However, it can apply to regular training and professional education through training courses, scientific seminars, workshops and conferences for engineers and technicians, and even energy and transport decision-makers, which help to understand cultural, environmental and technological facts in these fields.

CHAPTER 6
CONCLUSIONS

6.1 Conclusions

Both population and industrial growth are causing significant increases in energy demand throughout over Lebanon, especially in terms of electricity demand, which means there is a considerable need to find alternative sources to replace the traditional energy sources produced by fossil fuels. As a result, it is important to investigate the potential of solar energy at five coastal cities in Lebanon. For the future installation of PV in Lebanon, the solar energy potentials of five chosen cities were assessed using NASA's average monthly solar radiation. The results indicated that Tripoli has the highest global solar radiation with a value of 65.92kWh/m^2/day. Furthermore, it was noticed that all selected areas have high solar resources and are categorized as excellent, outstanding or superb potential classes. Moreover, the purpose of the present study is to evaluate the feasibility of developing 12kW grid-connected commercial solar PV power project in Lebanon. To fulfill this objective, RETScreen Expert software was used to validate the techno-economic and environmental sustainability of installing a grid-connected PV system in the country. Mono-Si - SF160-24-1M170 module manufactured by Hanwha Solar One Company was selected as an efficient PV for the proposed solar PV project. The results showed that the solar system in Tripoli city has the highest capacity factor of 22.5% when compared with the solar systems of other cities. Additionally, the annual energy exported to the grid varied between a minimum of 19.684MWh in Beirut city and a maximum of 23.765MWh Tripoli city and this affects the annual electricity exported revenue of the cities. Overall, with recent significant cost reductions and technological advances in PV sector as well as new encouraging policies established by Lebanon's ministry of energy, development of grid connected PV power plants in the country shows a huge potential and actual market opportunity for investors.

In the current study, solar PV power technology has been only studied, showing a good prospect of electricity generation in Lebanon. Furthermore, hybrid technologies (combination of two or more different technologies such as wind and PV) should be considered in order to make the renewable based technologies more feasible. This is why;

similar studies are required in future for climatic condition of Lebanon that should include combinations of different renewable technologies.

REFERENCES

Abdeladim, K., Bouchakour, S., Arab, A. H., Amrouche, S. O., & Yassaa, N. (2018). Promotion of renewable energy in some MENA region countries. *IOP Conference Series: Earth and Environmental Science, 154,* 012003. doi:10.1088/1755-1315/154/1/012003

Bergasse, E., Paczynski, W., Dabrowski, M., & Wulf, L. D. (2013). The Relationship between Energy and Socio-Economic Development in the Southern and Eastern Mediterranean. *SSRN Electronic Journal*. doi: 10.2139/ssrn.2233323

Chedid, R., Chaaban, F., & Salameh, S. (2001). Policy analysis of greenhouse gas emissions: The case of the Lebanese electricity sector. *Energy Conversion and Management, 42*(3), 373-392. doi:10.1016/s0196-8904(00)00060-1

Chel, A., & Kaushik, G. (2018). Renewable energy technologies for sustainable development of energy efficient building. *Alexandria Engineering Journal, 57*(2), 655–669. doi: 10.1016/j.aej.2017.02.027

Craddock, D. (2008). *Renewable energy made easy: free energy from solar, wind, hydropower, and other alternative energy sources*. Ocala, Fla: Atlantic Publishing Group.

Dursun, B., & Alboyaci, B. (2010). The contribution of wind-hydro pumped storage systems in meeting Turkeys electric energy demand. *Renewable and Sustainable Energy Reviews, 14*(7), 1979-1988. doi:10.1016/j.rser.2010.03.030

Edenhofer, O., Madruga Ramón Pichs, & Sokona, Y. (2012). *Renewable energy sources and climate change mitigation: special report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Foster, R., Ghassemi, M., & Cota, A. (2010). *Solar energy: renewable energy and the environment*. Boca Ratón, FL: CRC Press.

Greeley, R. S. (1976). *Energy use and climate: possible effects of using solar energy instead of "stored" energy*. Washington, U.S. G.P.O.

Green-Match. (2015). 7 Different Types of Solar Panels Explained. Retrieved October 1, 2019, from https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels.

Haas, R., Panzer, C., Resch, G., Ragwitz, M., Reece, G., & Held, A. (2011). A historical review of promotion strategies for electricity from renewable energy sources in EU countries. *Renewable and Sustainable Energy Reviews, 15*(2), 1003-1034. doi:10.1016/j.rser.2010.11.015

Haghi, E., Raahemifar, K., & Fowler, M. (2018). Investigating the effect of renewable energy incentives and hydrogen storage on advantages of stakeholders in a microgrid. *Energy Policy*, *113*, 206–222. doi: 10.1016/j.enpol.2017.10.045

Iodice, P., Daccadia, M. D., Abagnale, C., & Cardone, M. (2016). Energy, economic and environmental performance appraisal of a trigeneration power plant for a new district: Advantages of using a renewable fuel. *Applied Thermal Engineering*, *95*, 330–338. doi: 10.1016/j.applthermaleng.2015.11.017

Kang, S. H., Islam, F., & Tiwari, A. K. (2019). The dynamic relationships among CO2 emissions, renewable and non-renewable energy sources, and economic growth in India: Evidence from time-varying Bayesian VAR model. *Structural Change and Economic Dynamics*, *50*, 90–101. doi: 10.1016/j.strueco.2019.05.006

Kassem, Y., Gökçekuş, H., & Zeitoun, M. (2019). Modeling of techno-economic assessment on wind energy potential at three selected coastal regions in Lebanon. *Modeling Earth Systems and Environment, 5*(3), 1037-1049. doi:10.1007/s40808-019-00589-9

Krzyścin, J. W., & Jarosławski, J. (1997). Factors affecting solar UV radiation changes: a study of the new Robertson-Berger meter (UV-biometer model 501A) and Brewer data records taken at Belsk, Poland, 1993–1994. *Journal of Atmospheric and Solar-Terrestrial Physics*, *59*(10), 1133–1142. doi: 10.1016/s1364-6826(96)00107-1

Kuik, O., Branger, F., & Quirion, P. (2019). Competitive advantage in the renewable energy industry: Evidence from a gravity model. *Renewable Energy*, *131*, 472–481. doi: 10.1016/j.renene.2018.07.046

Lian, J., Zhang, Y., Ma, C., Yang, Y., & Chaima, E. (2019). A review on recent sizing methodologies of hybrid renewable energy systems. *Energy Conversion and Management*, *199*, 112027. doi: 10.1016/j.enconman.2019.112027

Marsh, J. (2019, June 25). Solar Cells: Everything to Know About Photovoltaics: EnergySage. Retrieved November 2, 2019, from https://news.energysage.com/how-solar-photovoltaic-cells-work/.

Michaelides, E. E. (S. (2014). *Alternative Energy Sources*. Berlin: Springer Berlin.

Misak, S., & Prokop, L. (2018). *Operation Characteristics of Renewable Energy Sources*. Cham: Springer International Publishing.

Nalule, V. R. (2018). Energy Access in Sub-Saharan Africa. *Energy Poverty and Access Challenges in Sub-Saharan Africa*, 21–39. doi: 10.1007/978-3-319-95402-8_2

Owolabi, A. B., Nsafon, B. E., Roh, J. W., Suh, D., & Huh, J. (2019). Validating the techno-economic and environmental sustainability of solar PV technology in Nigeria using RETScreen Experts to assess its viability. *Sustainable Energy Technologies and Assessments, 36*, 100542. doi:10.1016/j.seta.2019.100542

Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, *3*(1). doi: 10.1080/23311916.2016.1167990

Pawłowska, B. (2017). Alternative Fuels In TransportAs Energy Security Factor In European Union. *Zeszyty Naukowe Uniwersytetu Gdańskiego. Ekonomika Transportu i Logistyka*, *72*(0), 65–84. doi: 10.5604/01.3001.0010.6876

Pode, R. (2013). Financing LED solar home systems in developing countries. *Renewable and Sustainable Energy Reviews, 25*, 596–629. doi: 10.1016/j.rser.2013.04.004

Sissine, F. J. (2006). *Energy efficiency and renewable energy legislation in the 109th Congress*. Washington, D.C.: U.S. Library of Congress, Congressional Research Service.

Toklu, E. (2013). Overview of potential and utilization of renewable energy sources in Turkey. *Renewable Energy, 50*, 456–463. doi: 10.1016/j.renene.2012.06.035

Unesco, U. (2010). *Engineering: issues, challenges and opportunities for development*. Paris: UNESCO Publishing.

Zohbi, G. A., Hendrick, P., & Bouillard, P. (2015). Wind characteristics and wind energy potential analysis in five sites in Lebanon. *International Journal of Hydrogen Energy, 40*(44), 15311-15319. doi:10.1016/j.ijhydene.2015.04.115

APPENDICES

APPENDIX 1

ETHICAL APPROVAL LETTER

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APROVAL DOCUMENT

Date: 24/08 /2020

To the **Graduate School of Applied Sciences**

The research project titled “Viability Study Of Grid-Connected Rooftops Solar PV System for Different Coastal Cities in Lebanon’’ has been evaluated. Since the researcher(s) will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

Title: Assist. Prof. Dr.

Name Surname: Youssef Kassem

Signature:

Role in the Research Project: Supervisor

Title:

Name Surname:

Signature:

Role in the Research Project: Co-Supervisor

APPENDIX 2

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